AD-A128 010 BRIDGE WOUND WEB MODULE(U) EDO CORP SALT LAKE CITY UT FIBER SCIENCE DIV 1983 1/2

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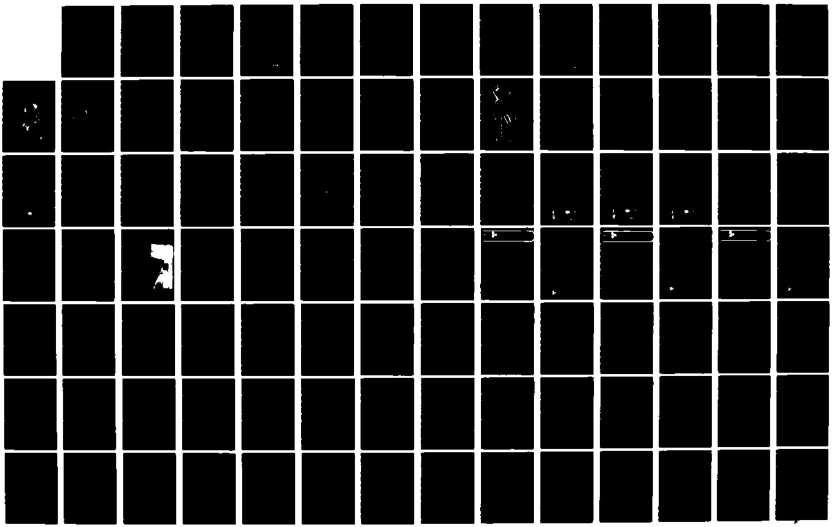

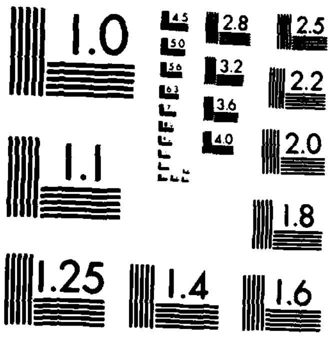

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DOCUMENT NUMBER

SA 3032J0003

BRIDGE WOUND WE3 MODULE

FINAL REPORT

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

EDO CORPORATION

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

DOCUMENT NUMBER

SA 3032J0003

BRIDGE WOUND WEB MODULE

FINAL REPORT

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REV STATUS	REV																								
OF SHEETS	SHEET																								

DRAWN	
CHECK	
STRESS	
WEIGHT	
Q.C.	
MFG ENGR	
PROJ ENGR	
PROJ MGR	
APPROVAL	7-4-83
APPROVAL	5-4-83
RELEASE DATE	

EDO CORPORATION FIBER SCIENCE DIVISION

TITLE

SIZE	CODE IDENT	DWG NO	REV
A	32500		

SCALE:	UNIT WT:	SHEET	OF

The views, opinions, and/or findings contained in the report are those of the authors and should not be construed as an official Department of the Army position, policy, or a decision, unless so designated by other communication.

1.0 INTRODUCTION

This effort was undertaken in order that feasibility, design and fabrication methods may be established for the manufacture of two wound web bridge module prototypes. Each wound bridge module consists of four webs a tread plate, and a bottom chord. The tread plates and the bottom chords were government furnished under the contract. Fiber Science proposed a production process of filament winding all four of the composite bridge webs at once on an aluminum diamond shaped mandrel which would fold out into the "W" shape which the four webs of each module would assume when the module was assembled. (See Figure 1.) This full scale mandrel would be a hinged weldment with relatively tight tolerances for such a structure. Cost estimates were near $125,000 for the mandrel alone. In order to reduce the cost, Fiber Science proposed to demonstrate process feasibility on a temporary, shortened wooden mandrel. Design feasibility demonstration was proposed by construction and testing of two full sized modules by an altered manufacturing method. Filament winding the mandrel skins on a pre-existing cylindrical mandrel, removing the skins from the mandrel, and then laminating these skins into the web configuration on a flat table would eliminate the need for an expensive mandrel. This method is more labor intensive and therefore less suitable for production than the filament wound "W" concept, but less costly for this demonstration phase. Modules manufactured by either method would meet design requirements. These prototypes were to be of composite materials in order to reduce the weight of the pre-existing all-aluminum bridge design. The work was approached in three phases.

Phase I, component development, included (1) material selection, (2) module concept refinement, and (3) trade-off studies. The Phase I Report was completed December 8, 1981 and submitted to the Army at that time.

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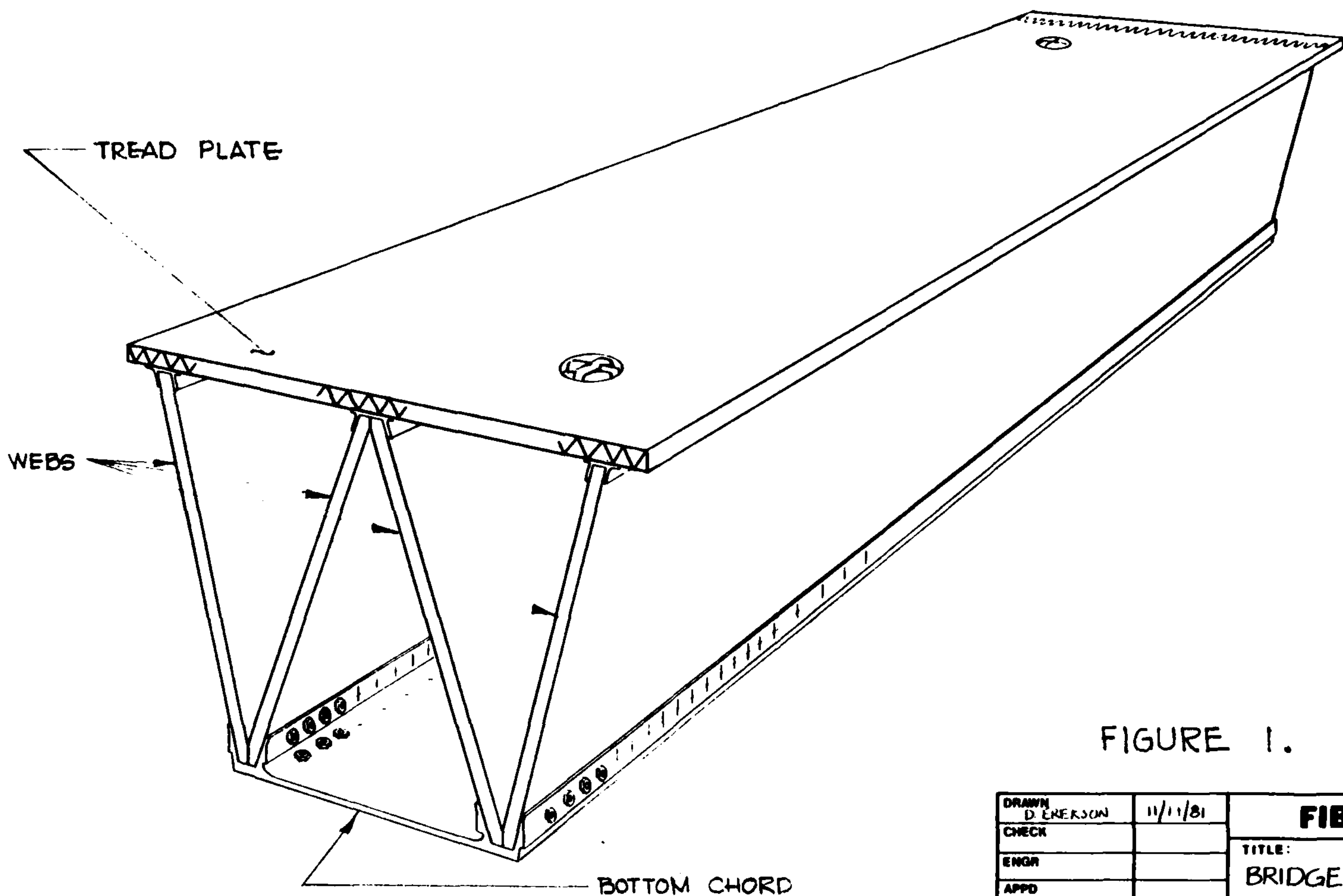

FIGURE 1.

DRAWN D. EMERSON	11/11/81	FIBER SCIENCE, INC.
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ENGR		
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Phase II, engineering design and documentation, included the creation of engineering drawings, manufacturing procedures, and test samples which were representative of the bridge module design. The samples were tested to failure to provide confidence in the wound web design. Design drawings, manufacturing procedures, and tests were completed and submitted with the Phase II Report on 13 August 1982.

Phase III of the effort consists of fabrication of eight wound bridge webs in full scale and the assembly of the webs with hardware for one complete interior bridge bay. The fabrication details for the wound bridge webs and associated hardware are included in this report.

II. RESULTS AND CONCLUSIONS

~~1.~~ The filament wound process for the manufacture of a bridge web was demonstrated to be both feasible and practical. This program identified some process modifications that are required for low cost production. (~~See Figure~~ 3) The modified process will retain the attractive features of the "wound W" process (~~see Figures~~ 4 and 5), but will greatly reduce tooling costs and improve producibility resulting in lower labor costs.

2. The winding angle may be modified from 45° to 50° to improve the winding pattern without impacting the structural integrity, but should be left at 45° for maximum strength at minimum thickness. (See Addendum IV.)

3. The design requirements for edge filler are met by the syntactic foam which Fiber Science used. This foam reduced the weight by an average of eight pounds per web over the weight of solid epoxy resin edge filler. Tests of the syntactic foam compressive strength, although high enough to meet design requirements, were not as high as anticipated.

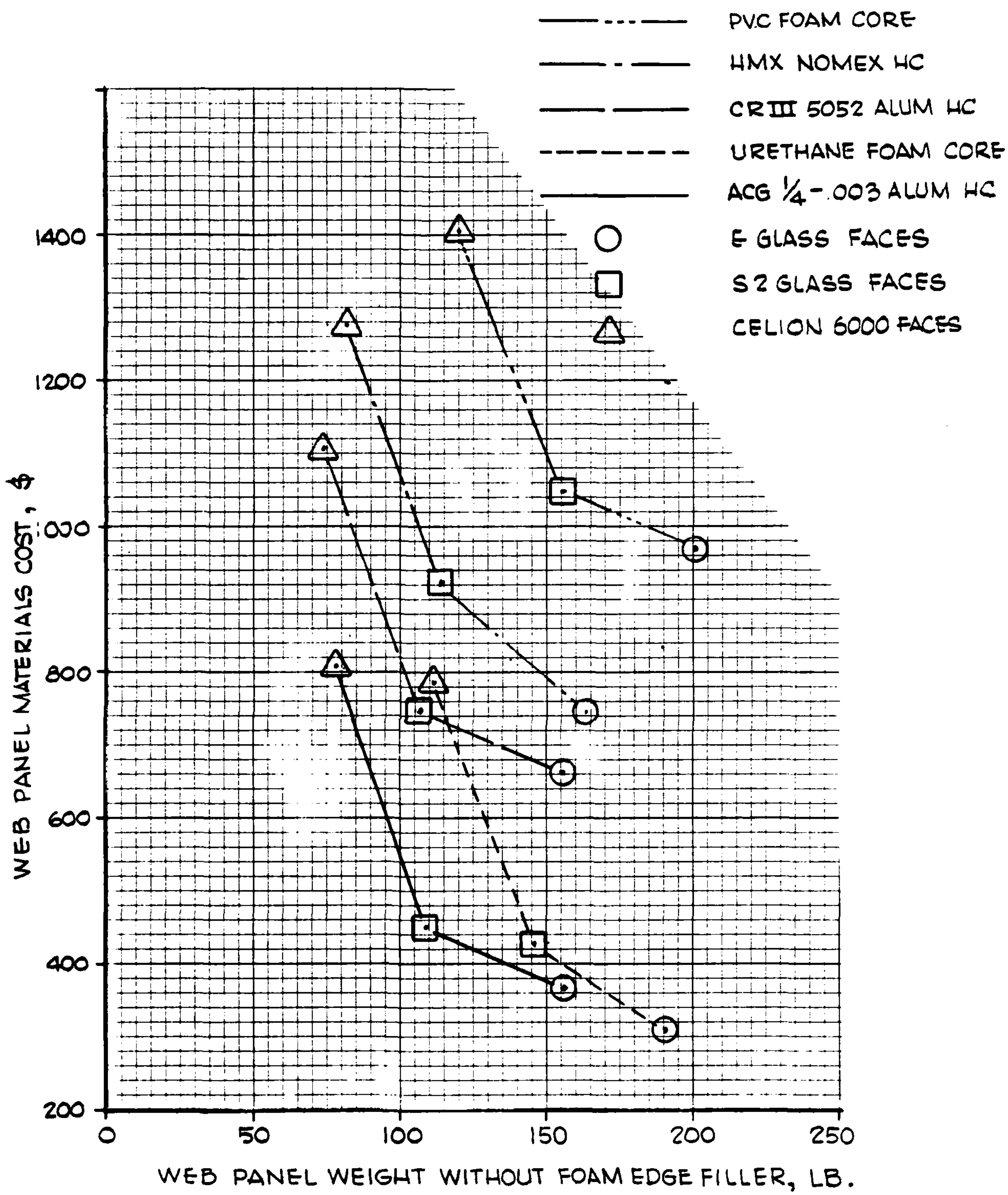

FIGURE 2. BRIDGE WEB MATERIALS SELECTION

ENGR.	TWITCHELL	1/19/83	REVISED	DATE	EDO CORPORATION FIBER SCIENCE DIVISION	REPORT
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The compressive test result was 3900 psi avg. 3M Company "Scotchply" XP-241 syntactic foam conforming to MIL-S-24154A Type I with a foam density of 38 pounds per cubic foot is reported* to have a yield strength of 5000 psi. Foam conforming to the same Mil spec in a 44 pound per cubic foot density is reported* to have a compressive yield strength of 10,000 psi. Unfilled epoxy resin has a density of 72.63 pounds per cubic foot. The foam used by Fiber Science was 39 pounds per cubic foot. It is recommended that the density of the foam be increased to 44 pounds per cubic foot in order to obtain higher compressive strength.

4. Results and conclusions from Phases I and II may be found in Addenda I, II and III.

III. PERFORMANCE

Fiber Science Division has complied with the requirements of Section C of the contract. The work required by Contract Section C.2.a, Concept Development, was performed and reported as Phase I of the effort. The Army response to the Phase I Report with its attendant instructions may be found in Addendum II of this report. Figure 1, of the Phase I Report, has been modified at Army request to show web panel cost and weight, with costs for graphite-epoxy representative of the materials used in Phase III. The revised Figure 1 is included as Figure 2 in this report. The Phase II effort as required by Contract Section C.2.b, Engineering Design and Documentation, may be found in Addendum III of this report. The Phase III effort as required by Contract Section C.2.c, Hardware Fabrication, is reported in this section.

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*Testing reported in "Scotchply" XP-241 Syntactic Foam Technical Data Sheet #11, dated January 1969.

IV. PHASE III REPORT, HARDWARE FABRICATION

This phase of the contracted effort was defined as the manufacture of the bridge module in full scale as defined by the design resulting from Phases I and II. The drawings which described the design were as follows:

DRAWING NO.	TITLE
3032P0001 REV-1	TOP ASSEMBLY BRIDGE WEB
3032A0004 REV-2	OUTER PANEL
3032A0005 REV-2	INNER PANEL
3032A0008 REV-1	LUG, TREAD PLATE
3032A0011 REV-1	CUP, BULKHEAD
3032A0012 REV-1	BULKHEAD
3997C5000 N/C	EXTRUSION, UPPER-CENTER
3997C5001 N/C	EXTRUSION, UPPER-END
3997C5002 N/C	EXTRUSION, LOWER CHORD

A. MANUFACTURING WEBS

The materials and process used to manufacture the composite webs are state of the art technology as described in the following sections.

A.1 MATERIALS

The materials which became a component of the end item webs are listed in Table I.

TABLE I MATERIALS

MATERIAL	MFG. BY	MFG. NAME	APPROX WT. PER WEB
HIGH STRENGTH CARBON FIBER	CELANESE CORPORATION	CELION 600	30.8 LBS.
EPOXY RESIN	SHELL CHEM.	EPON 826	15.2 LBS.
EPOXY RESIN HARDENER	UNIROYAL	TONOX LC	6.7 LBS.
GLASS CLOTH	J.P. STEVENS	120 CLOTH	3.0 LBS.
ALUM. HONEYCOMB	HEXCEL	ACG 3/8 - .003	31.0 LBS.
SYNTACTIC FOAM	FIBER SCIENCE		41.3 LBS.
		TOTAL WEB WEIGHT	128.0 LBS.

The sytactic foam was made from the following formula:

SHELL 826 RESIN	100 PARTS BY WEIGHT
ANCAMINE LO HARDENER	25 PARTS BY WEIGHT
ANCAMINE LOS HARDENER	25 PARTS BY WEIGHT
GLASS MICROBALLOONS	42 PARTS BY WEIGHT

This system was used in order to eliminate one high temperature cure from the process. Six samples of this syntactic foam were compression tested to obtain an average strength of 3,900 psi, compared to 9,000 - 10,000 psi for unfilled epoxy resin. The foam density as used was 0.023 lb/in^3, using glass microballoons type B23/500 made by 3M Company. The compressive strength of the syntactic foam was lower than anticipated because a high percentage of glass microballoons was used, creating a low density syntactic foam, and therefore a low compressive strength syntactic foam. The compressive strength obtained was still high enough to survive the design loads, but could be increased with little weight penalty. The hardeners are manufactured by Pacific Anchor Chemical Company.

The aluminum extrusions used to attach the webs to the tread plate and to the bottom chord were extruded by Kaiser Aluminum from 6061 aluminum stock in the "0" condition and subsequently heat treated to the T-6 condition.

Bulkheads were manufactured from the same resins as the web, but the reinforcement was high strength carbon woven fabric Style W-133, made by Fiberite Corporation. The honeycomb used in the bulkhead was ALH-CG/3003 commercial grade honeycomb by Unicel Corporation, with a thickness of 0.50 inches.

Glass cloth insulation was bonded to the composite faces where intimate contact was expected between aluminum and carbon. The intent of this design feature is to break up any galvanic cell which might corrode the aluminum in contact with carbon. Further corrosion prevention was provided by installing stainless steel fasteners wet with a strontium chromate primer coating. The sacrificial primer was purchased to military specifications MIL-P-23377 Type I.

A.2. WEB MANUFACTURING PROCESS

The bridge web manufacturing process was studied in Phase I of this project. The recommendation made on page 7 of Phase I Report was to hand layup the entire web from "Knytex" a brand name of commercially preplied broadgoods. The government position taken in response to the Phase I Report requeseted determination of the actual cost of the "Knytex" fabric made with low cost graphite fiber. Careful comparison of graphite "Kyntex" was made with the filament wound "W" process to determine which is less costly. The "W" process (see Figure 4 and 5) which was first presented in the Fiber Science proposal for this work, is direct filament winding

FIGURE 3

BASELINE CONCEPT

WOUND "W" WEB PANEL ASSY CONCEPT

(SINGLE WOUND PART FOR WEB ASSY.)

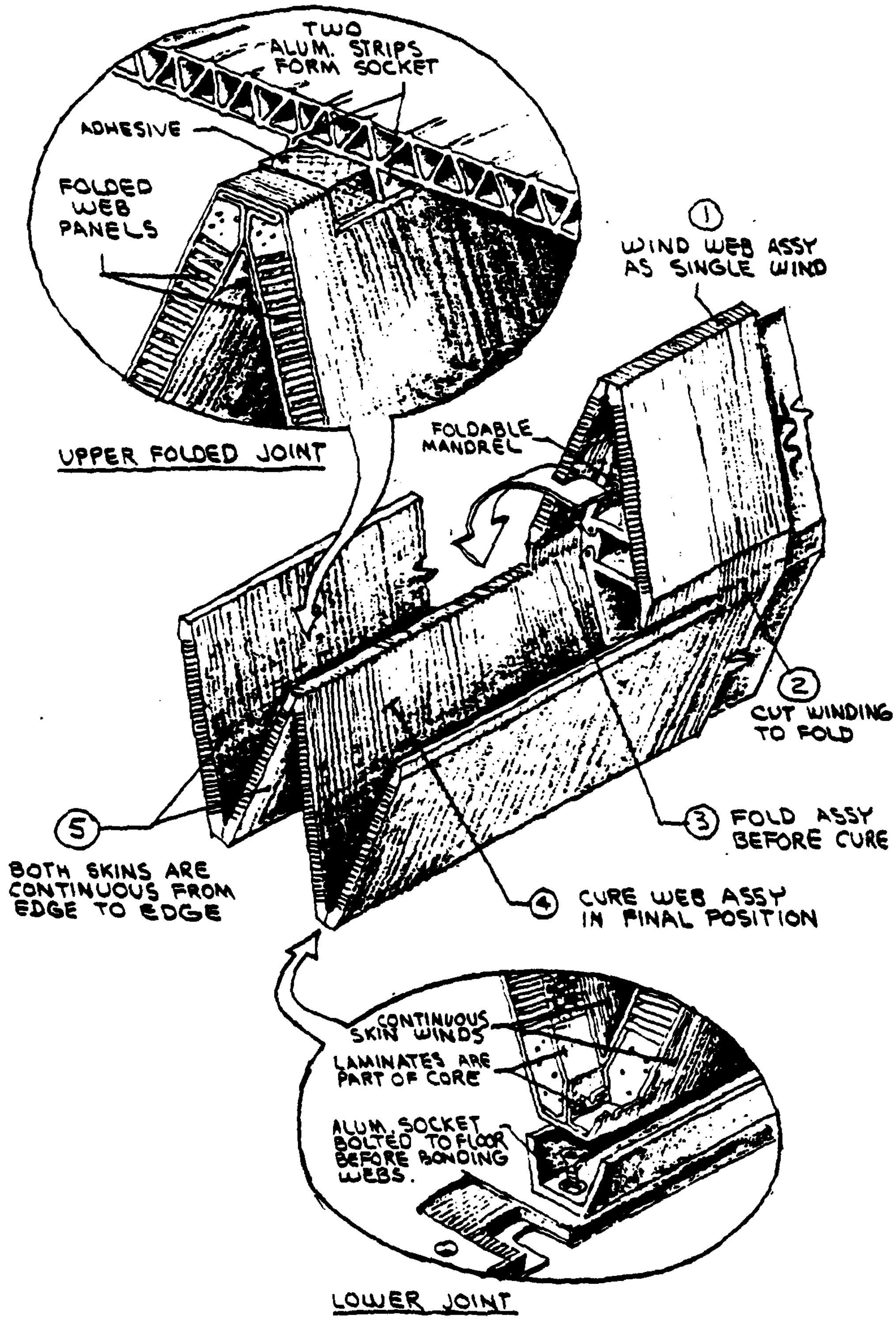
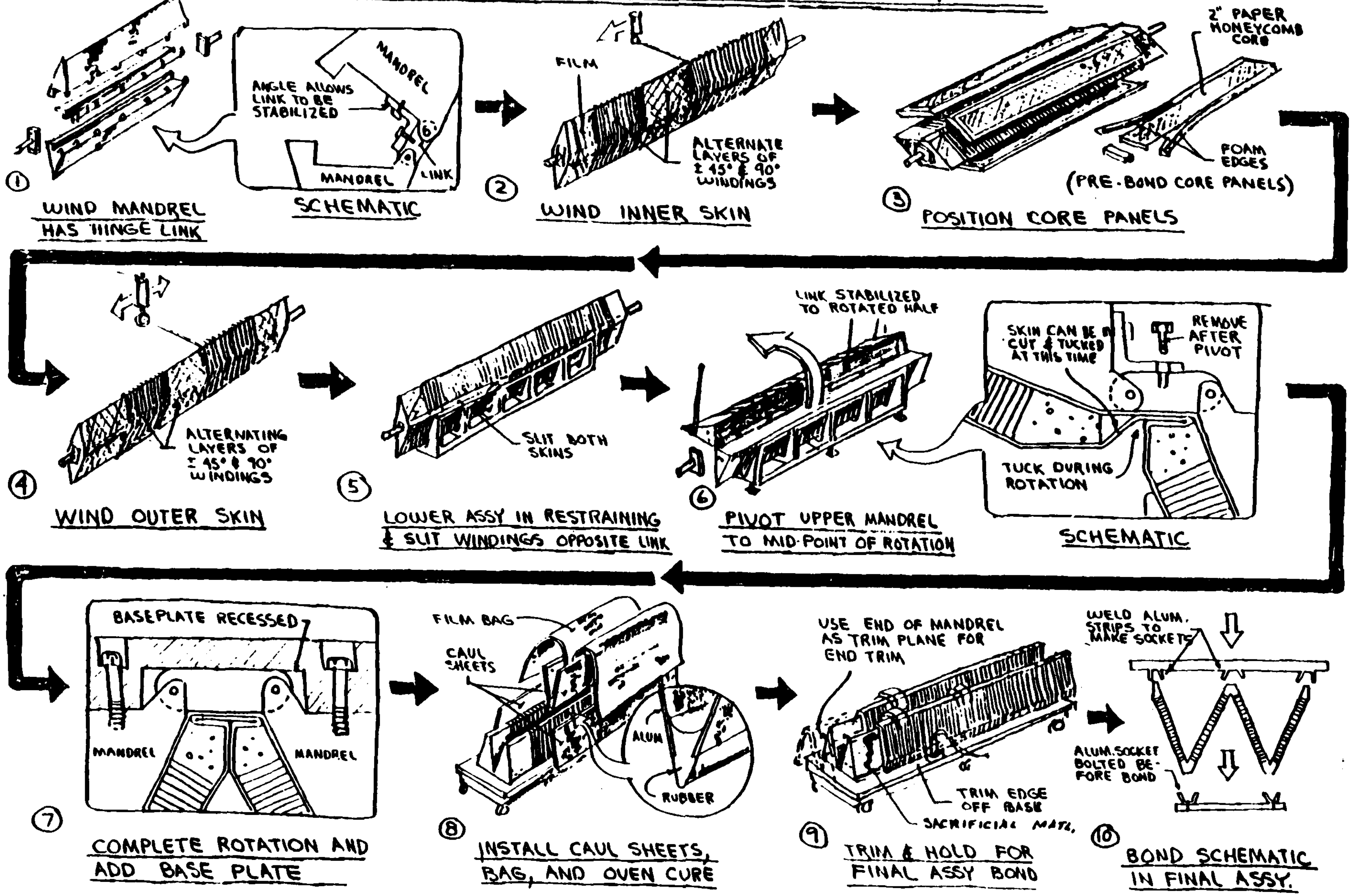


FIGURE 4 WOUND "W" WEB ASSY. FABRICATION SEQUENCE



upon a diamond shaped mandrel. In that process the windings were slit along one side and folded out into a "W" after the windings were "B" staged.

During the Phase II work, more detailed cost estimates revealed that knitting machine setup and material waste charges would indeed make the "Knytex" process more expensive that the "W" process The latter process was, therefore, selected for the production process. Cost estimates for a full scale mandrel to be used for fabrication of the eight webs funded on the contract ranged near $125,000. This cost was not included in the Fiber Science proposal, which only contained $6,808 for tool materials and construction labor. The mandrel proposed was a shortened wooden mandrel as discussed in the introduction. To make a full size mandrel twenty-three feet long which does not sag in the middle requires stiffer, less dense materials than wood and results in the high price. The demonstration winding manufacturing process used to evaluate the two approaches was as follows:

1. Phase III web skins were filament wound on a large existing cylindrical mandrel, cut and laminated into the web configuration complete with honeycomb core.
2. A scaled down wooden mandrel was fabricated to demonstrate both winding techniques for the diamond shaped mandrel and the slitting and folding operation. The demonstration mandrel was full sized in cross section but the length was reduced to six feet from the twenty-three feet required for a full scale web.

A.3. FULL SCALE WEB MANUFACTURE

The web skins were wound on a cylindrical mandrel 38 inches in diameter. The mandrel was first wrapped with a plastic sheet. Hoop windings were made with a 1.0 inch wide band consisting of 13 rovings. The helical windings were 16 rovings in a 1.0 inch wide band.

When the skin winding was complete, the skin, with the plastic sheet carrier, was slit and peeled off the mandrel so that it could be laid flat on a work table. The curvature of the mandrel causes some wrinkling in the outside fibers of the skin when the skin is laid flat, so some hand work was performed to remove wrinkles. The skin was "B" staged 24 hours at room temperature before further handling.

After "B" staging, the skin could be bonded to the aluminum honeycomb core. A layer of peel ply was applied to the work table, followed by the skin and then 120 glass cloth was applied to the skin dry, and then wet out with resin. Four honeycomb panels, each cut to drawing width and six feet long, were then positioned on top of the glass cloth, and butted together. The assembly was then vacuum bagged to the work table and cured. The cure cycle was as follows:

4	Hours	150° F
4	Hours	225° F
4	Hours	275° F
1.5	Hours	Cool With Oven Doors Closed

After the first skin cured, the vacuum bag was removed, and the honeycomb cells were filled with syntactic foam around the periphery of the web. The filled area was 1.5 inches wide. The honeycomb butt joints were also filled 0.75 inches wide. The formula for mixing the syntactic foam was given in the materials section of this report.

In practice it was found that the mixture was thin enough to be poured into the cells. After pouring, the table was tapped or vibrated in order to bring bubbles to the top Bubbles were scraped off the top and cells were completely filled before foam was cured.

Following foam installation the partial assembly was removed from the work table. The second skin was then bonded to the honeycomb partial assembly in the same manner as the first skin: the skin was placed over a peel ply (to provide a paintable texture), the 120 glass cloth layer applied dry on top of the skin, and then the partial assembly was vacuum bagged down to the skin, followed by the cure. Bonded assemblies were then trimmed to length and stored to await final assembly.

B. METAL HARDWARE

The new metal components were purchased by Fiber Science from vendors. The largest metal components were the aluminum extrusions used to attach webs to the tread plate and to the bottom chord. These extrusions, Drawing Numbers 3997C5000, 39975001 and 3997C5002 were custom manufactured for Fiber Science by Kaiser Aluminum in Los Angeles, California.

The cross brace attachment lugs, Drawing Numbers 3032A0008 and 3032A0011 were manufactured for Fiber Science by Heinhold Engineering of Salt Lake City to Fiber Science drawings.

Stainless steel bolts used to both attach webs to extrusions and bulkheads to webs were purchased by specification number to HRS Fasteners Company in Arlington, Texas. Stainless steel inserts for the bulkhead-to-web joint were purchased from Tridair Industries, Torrance, California.

C. BRIDGE MODULE ASSEMBLY

The module pieces were assembled in the following order so that bonding and bolt assembly might be performed conveniently.

1. Weld upper extrusions to tread plate
2. Drill bolt holes through both sides of extrusion using a drill press.
3. Prepare extrusion surface for bonding with pasa gel solution.
4. Bond inner webs into center extrusion socket using adhesive and
5. Drill web bolt holes through predrilled extrusion bolt holes.
6. Assemble bolts wet with MLP-P-23377 Type J Primer.
7. Bond outer webs into outer extrusion socket using APCO 2434/2310 adhesive and locating jigs.
8. Drill outer web bolt holes through predrilled extrusions.
9. Install bolts in outer extrusion-web joint wet with primer. Assemble bottom chord with lower extrusions.
10. Prepare lower extrusions for bonding with pasa gel solution.
11. Butter lower edge of webs with APCO 2434/2310 adhesive and bond lower chord assembly to webs using a locating jig.
12. Drill lower web bolt holes through predrilled extrusions
13. Install bolts in lower extrusion-web joint wet with primer.

The cross brace lugs were welded in position on the assembled bridge using a locating jig.

D. DEMONSTRATING WINDING

The demonstration winding portion of this effort was undertaken to show the production process for bridge webs proposed by Fiber Science is feasible. This winding demonstrated, the Army has at its disposal a production method which is largely automated and which is not labor intensive, thereby enhancing production rates and reducing costs A full scale winding would have been most convincing as a feasibility demonstration, but the cost of such a mandrel was prohibitive for this program. Full scale mandrel cost estimates were near $125,000. Since the major problems

were expected in turnaround (a form attached to the ends of filament winding mandrels to facilitate fiber direction reversal) design and mandrel folding, a shorter mandrel was considered to be a reasonable compromise. The turnaround problem would not be diminished by a short mandrel of full sized cross section but folding a short mandrel would be easier. As the demonstration winding progressed, the anticipated problems were found to be real but solvable. A discussion of the problems and problem solutions follow.

D.1 <u>TURNAROUNDS</u>

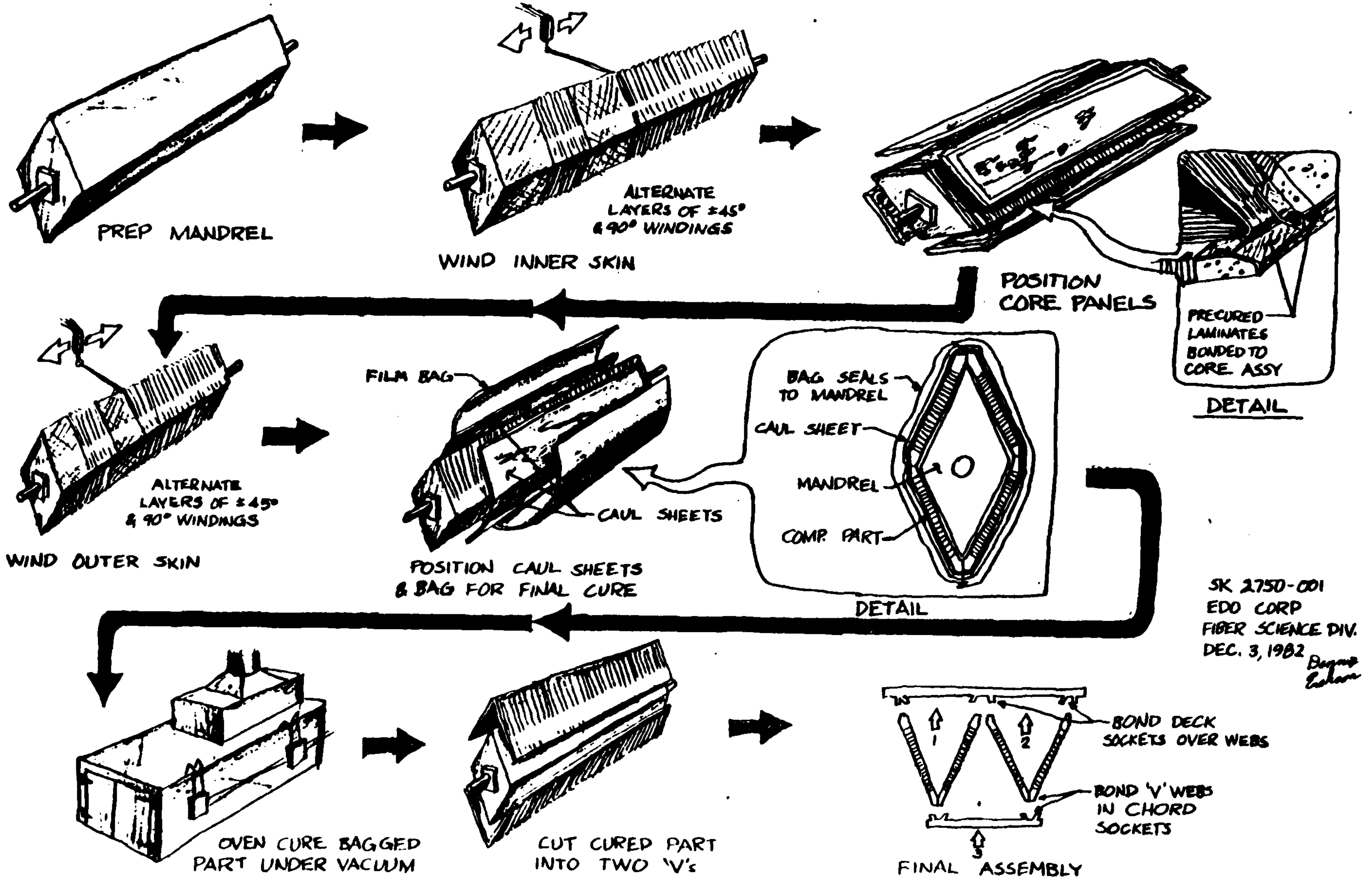
Several turnaround designs were tried before one was found which brought reasonable results. This turnaround design was obtained by calculating the perimeter length of the diamond portion of the mandrel and then determining the diameter of a circle which has the same circumference as the mandrel perimeter. The circle was cut from plywood and used as the end piece of the turnaround. The remainder of the turnaround contour was calculated. An existing mandrel stand was used which offered 28 inches on each end for turnaround. More distance, approximately 36 inches, would be required to provide a uniform winding pattern to the end of the mandrel at the $\pm 45^{\circ}$ winding angle designed in the web skin laminate. As a result, the $\pm 45^{\circ}$ winding in the inside skin of the demo piece were poorly distributed due to bridging and slipping of fibers during winding. A satisfactory winding pattern was obtained on the outer skin by changing the helical winding angle to 55°. Analysis reveals, however, that the winding angle should not be increased beyond 50° because of decreasing composite shear strength (see Addendum 1). A completely satisfactory turnaround would be achieved with proper tooling

D.2. MANDREL FOLDING

The difficulties with the folding operation began as soon as the slit was made (Figure 4). The skins and the honeycomb tended to fall away from the mandrel. Elastic cords were fastened around the mandrel halves to secure the webs to the mandrel, and still the webs sagged away from the mandrel between cords stretching the skins and causing wrinkles. As a result, it was decided that the cut shown in the Figure 2, Step 6 schematic would be deleted. The weight of the six foot long wooden mandrel made the tuck operation so awkward that it was poorly done and became a lump which crushed the honeycomb. The honeycomb has not been dimensionally stabilized and stretched during handling and folding so that it was caught and crushed as the fold was made. None of these problems was so serious that it could not be overcome with proper tooling and procedure After considering this process, Fiber Science has concluded that a variation of the wound "W" concept would require much less tooling and probably fewer manhours (see Figure 5), while retaining the most desirable features of the previous version, namely, low labor intensity and producibility.

FIGURE 5

BRIDGE WEB FABRICATION SEQUENCE



ADDENDUM IV

50° HELICAL

SAFETY FACTOR = 1.5

FATIGUE FACTOR = .615

% 90° FIBERS	F_{ycu} PSI	t_{web} IN.	F_{xyu} PSI	t IN
.90	143344	.0258	5700	.2285
.85	136688	.0270	7709	.1690
.80	130032	.0284	9718	.1340
.75	116720	.0316	13736	.0948
.70	110065	0336	15745	.0827
.65	103409	.0357	17754	.0734
.60	96953	.0381	19763	.0659
.55	90097	.0410	21772	.0598
.50	83441	.0443	23780	.0548
.45	76785	.0481	25788	.0505
.40	70129	.0527	27796	.0469
.35	63473	.0582	29804	.0437
.30	56817	.0650	31810	.0409
.25	50161	.0736	33815	.0385
.20	43505	.0849	35819	.0364
.15	36850	.1002	37818	.0344
.10	30194	.1223	39807	.0327

FOR 50^{o} HELICAL, 45% 90^{o} PLIES, TRY $t_{web} = .080$

$E_x = 2.136 \times 10^6$ $\qquad$ $G_{xy} = 2.506 \times 10^6$

$E_t = 8.940 \times 10^7$ $\qquad$ DENSITY = .0527

$= (.00202)(2.136 \times 10^6) = 4315$ psi

$= \dfrac{1514}{.080} = 18{,}925$ psi

$= \dfrac{534}{.080} = 6675$ psi

INTERACTIONS EQUATIONS

$$I = \left(\frac{4315}{.615\,(12473)}\right)^2 + \left(\frac{18925}{.615(76785)}\right)^2 - \left(\frac{4315(18925)}{.6152(12473)(76785)}\right) + \left(\frac{6675}{.615(25788)}\right)^2$$

$= .3164 + .1606 - .2254 + .1771$

$= 0.4287$

$$F.S. = \frac{1}{.4287} = 1.527$$

55o HELICAL

$F_{xcu} = 8315$ $F_{ycu} = 73866$ $F_{xy} = 25737$

%90° FIBERS	F_{ycu}	t	F_{xyu}	t
.90	137311	.0269	7377	.1766
.85	130966	.0282	9220	.1413
.80	124622	.0296	11062	.1177
.75	118277	.0312	12903	.1009
.70	111933	.0330	14743	.0883
.65	105588	.0350	16581	.0786
.60	99244	.0372	18418	0707
.55	92899	.0397	20253	.0653
.50	86555	.0427	22085	.0590
.50	80210	.0460	23913	.0545
.40	73866	.0500	25737	.0506
.35	67521	.0547	27553	.0473
.30	61176	.0604	29359	.0444
.25	54832	.0673	31150	.0418
.20	48487	.0762	32912	.0396
.15	42143	.0876	34622	.0376
.10	35798	.1032	36209	.0360

FOR 55^{o} HELICAL, TRY $t_{web} = 0.120$, 40% 90^{o} PLIES

$$x = 3454 \text{ psi}$$

$$y = \frac{1514}{.120} = 12{,}617 \text{ psi}$$

$$= \frac{534}{.120} = 4450 \text{ psi}$$

INTERACTION RELATIONSHIPS

$$I = \left(\frac{3454}{.615(8315)}\right)^2 + \left(\frac{12617}{.615(73866)}\right)^2 - \left(\frac{3454(12617)}{(.615)^2(8315)(73866)}\right) + \left(\frac{4450}{.615(25737)}\right)^2$$

$$= 0.4562 + 0.0771 - 0.1876 + .0790$$

$$= 0.4247$$

$$\text{M.S.} = \frac{1}{/4247} = \underline{\underline{1.5344}}$$

ADDENDUM I

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

DOCUMENT NUMBER

SA 3032-J-0001

TITLE

BRIDGE WOUND WEB MODULE
PHASE I REPORT

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MFG ENGR		
PROJ ENGR	[illegible]	12/7/81
PROJ MGR		
APPROVAL	J V Daines	12-[illegible]-81
APPROVAL		
RELEASE DATE	12-3-81	

FIBER SCIENCE, INC.
SALT LAKE CITY, UTAH 84116

TITLE
BRIDGE WOUND WEB MODULE
PHASE I REPORT

SIZE	CODE IDENT	DWG NO	REV
A	32500		

SCALE:	UNIT WT:	SHEET 1 OF 78

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I. INTRODUCTION

The Wound Bridge Web contract is an effort to reduce the weight of the existing bridge. The wound bridge web contract, which provides for the determination of contract feasibility, design, fabrication, test and assembly of two bridge web modules, was received at Fiber Science on September 28, 1981.

Phase I of the contract, Component Development, includes (1) material selection, (2) module concept refinement, and (3) trade off studies. Phase II of the contract will consist of engineering design and documentation. Phase III will be fabrication of hardware for one complete interior bridge bay and assembly of parts.

This is the final report under Phase I of the contract.

II. AIMS AND OBJECTIVES OF PHASE I

1. Determine weight versus cost for various material combinations and physical configurations which meet the requirements of Attachment I to the Statement of Work.

2. Determine cost of labor and materials for each of the candidate manufacturing methods proposed for large scale manufacture of the bridge webs.

3. Prepare recommendations based on cost, weight, fatigue strength, ease of manufacture and efficient material usage.

4. Prepare preliminary designs for bridge web, web attachments, bulkheads, and redesign cross braces if necessary.

5. Determine weight and cost of the recommended preliminary design in large scale production.

III. CONCLUSIONS & RECOMMENDATIONS

A. MATERIALS CONCLUSIONS

Material weight requirements were determined by going through the design procedure for each of the core material candidates in combination with each skin candidate. After thicknesses of core and facing materials had been calculated with the design procedure, the weight of each design in pounds per square inch was calculated. These weights were summarized in Table I and Figure I. The weights may be compared to the original design weight of 0.025 LB/IN^2.
Minimum weight combination was graphite-epoxy facing with one of the three aluminum core materials analyzed, and minimum cost combination was E-glass-epoxy facing with polyurethane foam core. The best compromise between minimum weight and minimum cost was S2 glass-epoxy with ACG 3/8-.003 aluminum core, at $\$.0062/FT^2$ and 0.0153 LB/IN^2. This alternative would offer a 57% decrease in weight of the original design for slightly less than $\$2/FT^2$ increase in cost.

TABLE I Mat'l Cost Comparison/Interior Bay

Original		Min. Cost		Min. Wt.		Compromise	
$	Wt,Lb	$	Wt,Lb	$	Wt,Lb	$	Wt,Lb
1141.	983.	1119.	731.	3006.	246.	1665.	425.

B. PROCESS CONCLUSIONS

A labor and materials comparison was made for each of four proposed producation methods:

Option A. Filament wind entire skin.

Option B. Filament wind broadgoods and layup.

Option C. Filament wind 90^0 ply only, layup Knytex* for 45^0 plies.

Option D. Hand layup entire web from Knytex*.

* Knytex CDB to be manufactured to width and thickness desired. This is a nonwoven triaxial fabric.

Two major breakdowns were made in labor and materials comparison: "W" represents the baseline "Wound W" concept presented in the proposal where faces were wound over a diamond shaped mandrel with subsequent face slitting and mandrel folding operations to produce the "W" form desired. "V" represents using a "V" shaped mandrel to produce one-quarter of the interior bay web section at a time. This method would have a 32% waste of facing materials inherent to the process.

Table II, which follows, summarizes relative costs for the process options.

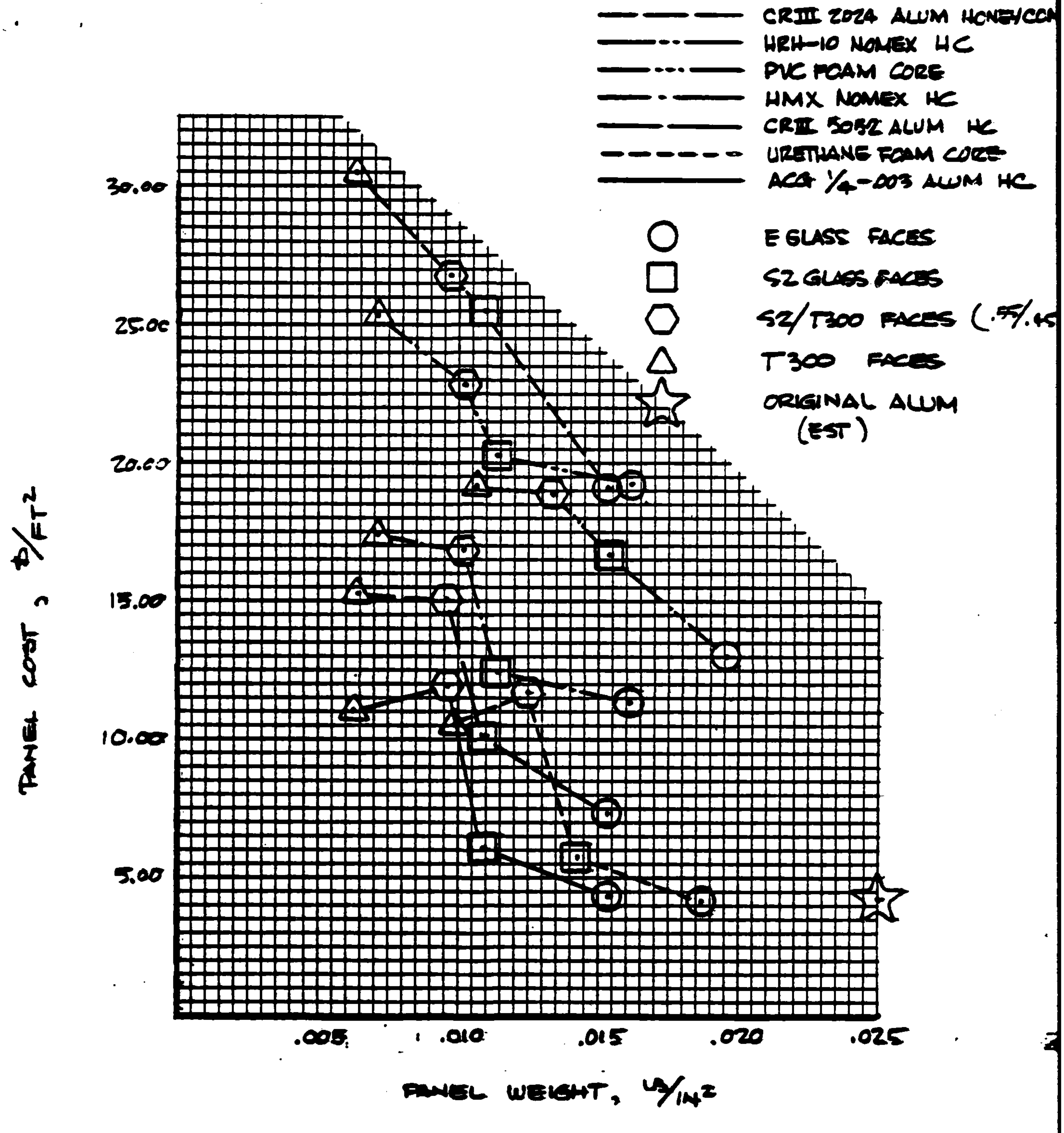


FIGURE I

ENGR.	TWITCHELL	11/4/81	REVISED	DATE	BRIDGE WEB MATERIALS SELECTION	
CHECK						
APR						
APR					FIBER SCIENCE, INC.	

FSI-100-4/79

C. DESIGN CALCULATIONS CONCLUSIONS

1. During the design calculations phase it became evident that the design "driver" was the composite shear modulus, G, of the core material.

2. Hybrid composites, or combinations of fiber materials in the faces of the web did not prove to be an advantage because of the well known effect of mismatched modulus materials: Using a high modulus with a lower modulus material causes premature loading and failure of the stiffer material.

3. Low compression strength of Kevlar 49 prompted its deletion from the list of facing materials.

D. RECOMMENDATIONS

1. Use the S2 Glass-Epoxy/ACG Aluminum Core combination for web materials.

2. Use the hand layup Option D process for production manufacture of the webs.

3. Class C drawings will be generated for phase III of the present contract. (See para. B.5 of FSI Management Procedure 200-1.)

4. Tool drawings for the present contract will be type 1 for vendor use and type C for in house use. (See para. B.5 of FSI Management Procedure 200-1.)

5. The level of fabrication to be used for the present contract in-house needs will be level I. (See para.6,para.E.1 of M.P. 200-1.)

6. Tooling fabrication will be class "C" and class "D".(See para.14 of M.P.400-03.

7. Bridge web panels manufactured on Phase III of this contract will be non-interchangeable.

E. DESIGN CONCEPT SKETCHES

The attached sketches, figures II, through V, represent attachment concepts which are consistent with design calculations. In general, attachment fittings will be aluminum extrusions which are anodized for corrosion protection, and are both bonded and bolted to the web in order to provide a reliable structure. Extrusions will be welded to the upper chord.

TABLE II.

"W" PROCESS COST DIFFERENCE, $/FT^2

Face Mat'l/Core Mat'l	A	B	C	D
		PROCESS OPTION		
E Glass/ACG	1.28	0.53	0.83	0.00
S2 Glass/ACG	3.01	2.26	2.96	2.38
T300/ACG	8.39	8.14	N.A.	18.02*

* Not believed to be a volume quote

"V" PROCESS COST DIFFERENCE, $/FT^2

Face Mat'l/Core Mat'l	A	B	C	D
		PROCESS OPTION		
E Glass/ACG	1.95	0.53	1.17	0.00
S2 Glass/ACG	4.05	2.26	3.48	2.38
T300/ACG	11.53	8.14	N.A.	18.02*

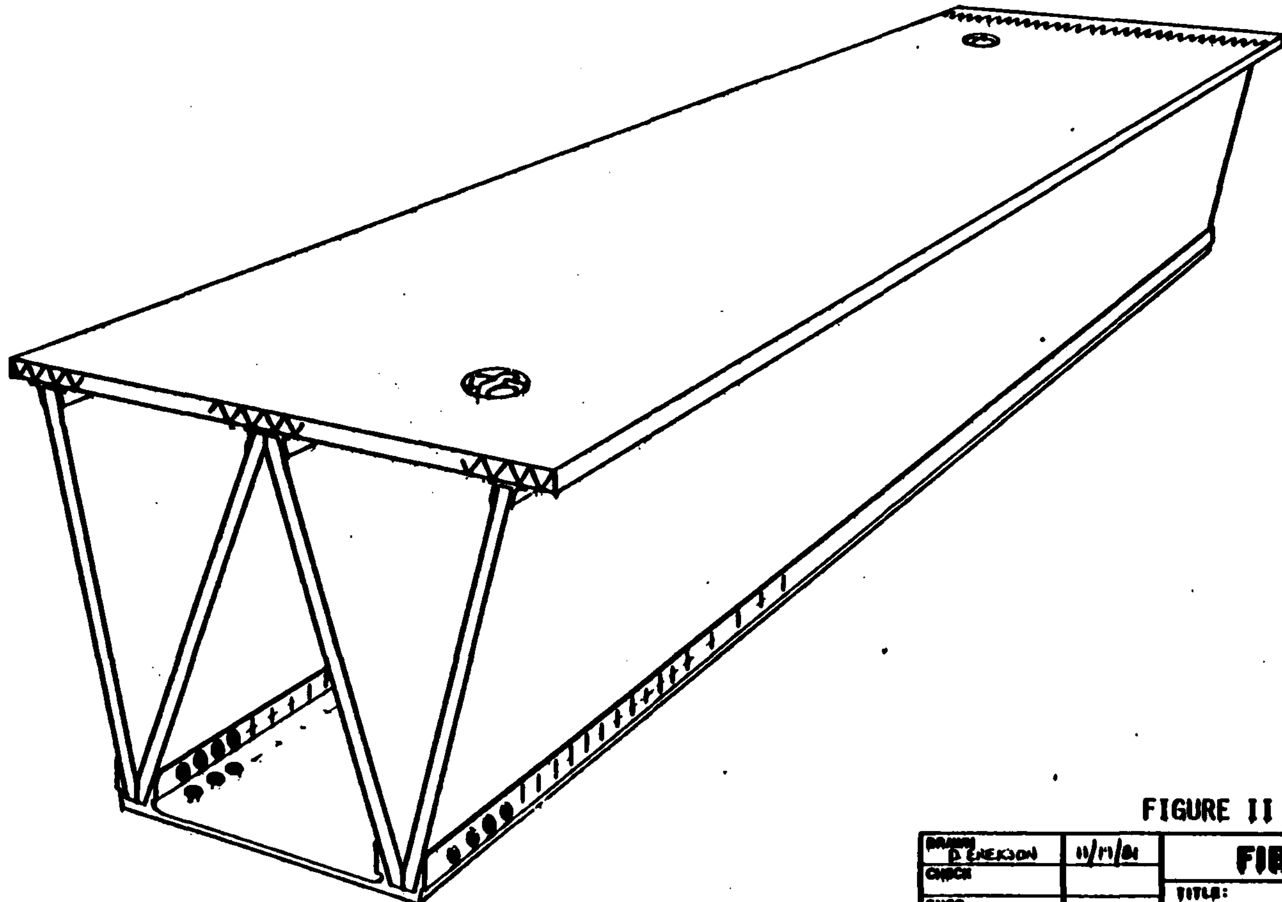


FIGURE II

REVISIONS			
LTR	DESCRIPTION	DATE	APPD

DRAWN D. ERICKSON	11/11/81	FIBER SCIENCE, INC.
CHECK		TITLE: BRIDGE WEB, PERSPECTIVE
ENGR		
APPD		
APPD		SKETCH NO. / REV
RELEASE DATE :		

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

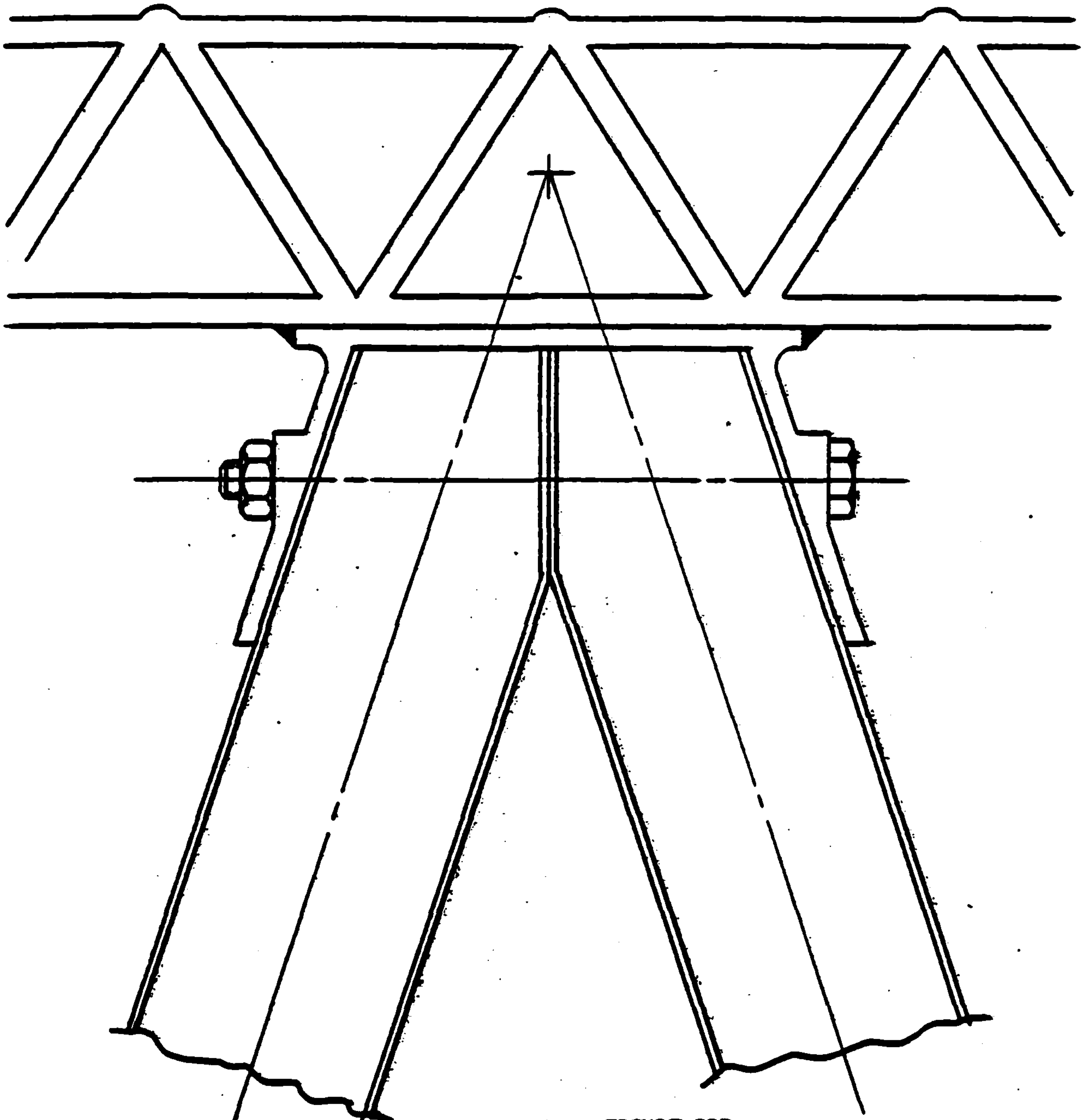


FIGURE III

D. EREKSON	11/19/81	FIBER SCIENCE, INC. SALT LAKE CITY, UTAH 84110
		TITLE UPPER CHORD/WEB JOINT
C.G.		
APPROVAL		SIZE A · CODE IDENT 32500 · DWG NO. · REV
APPROVAL		
RELEASE DATE		SCALE: 1/1 · UNIT WT: · SHEET 10 OF

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

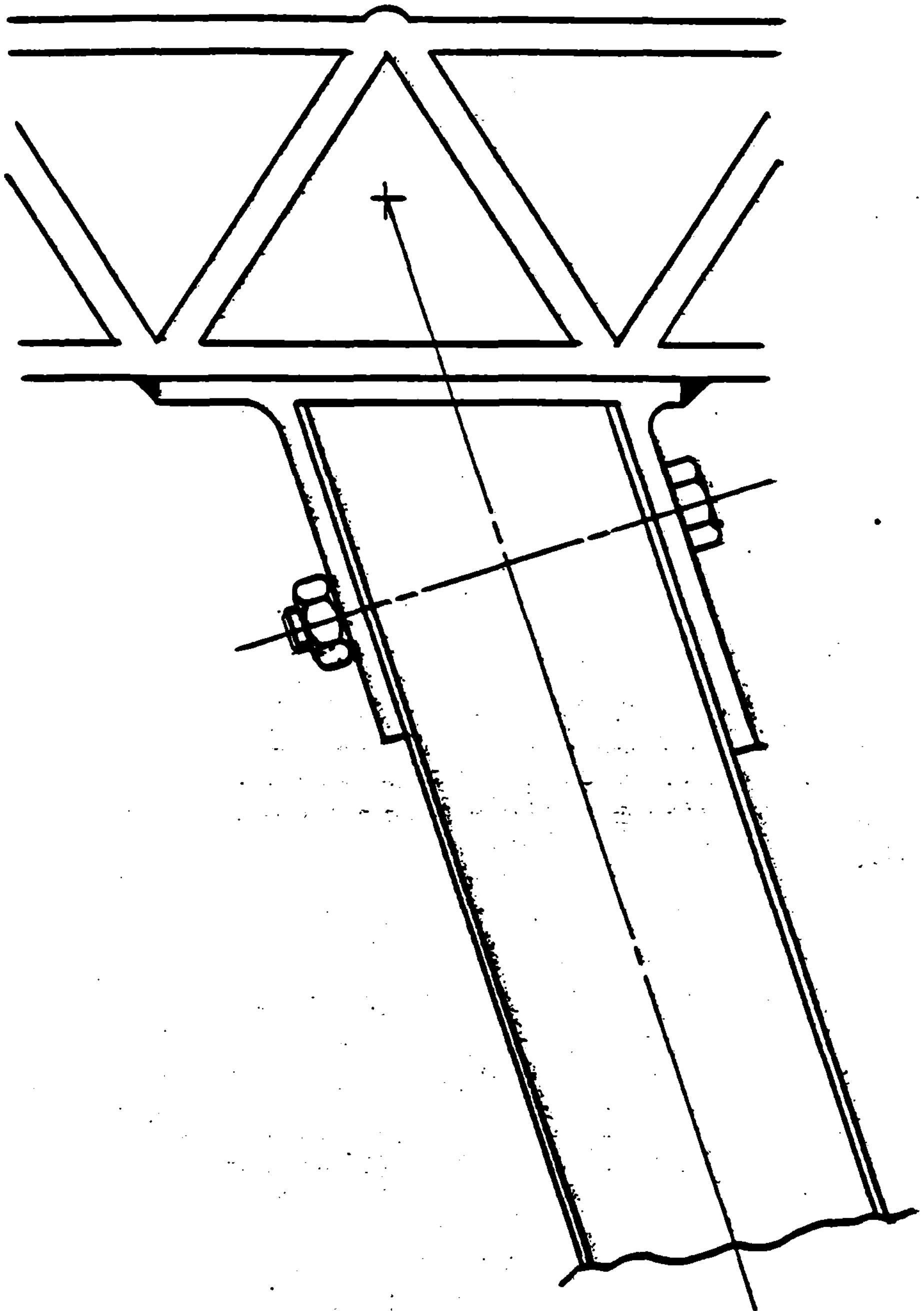


FIGURE IV

DRAWN D. ERICKSON	11/19/81	FIBER SCIENCE, INC. SALT LAKE CITY, UTAH 84116
CHECK		
STRESS		
WEIGHT		TITLE
Q.C.		UPPER CHORD/ WEB JOINT
MFG ENGR		
PROD ENGR		
PROD SUP		SIZE A — CODE IDENT 32500 — DWG NO — REV
APPROVAL		
APPROVAL		
RELEASE DATE		SCALE: 1/1 — UNIT WT: — SHEET 11 OF

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

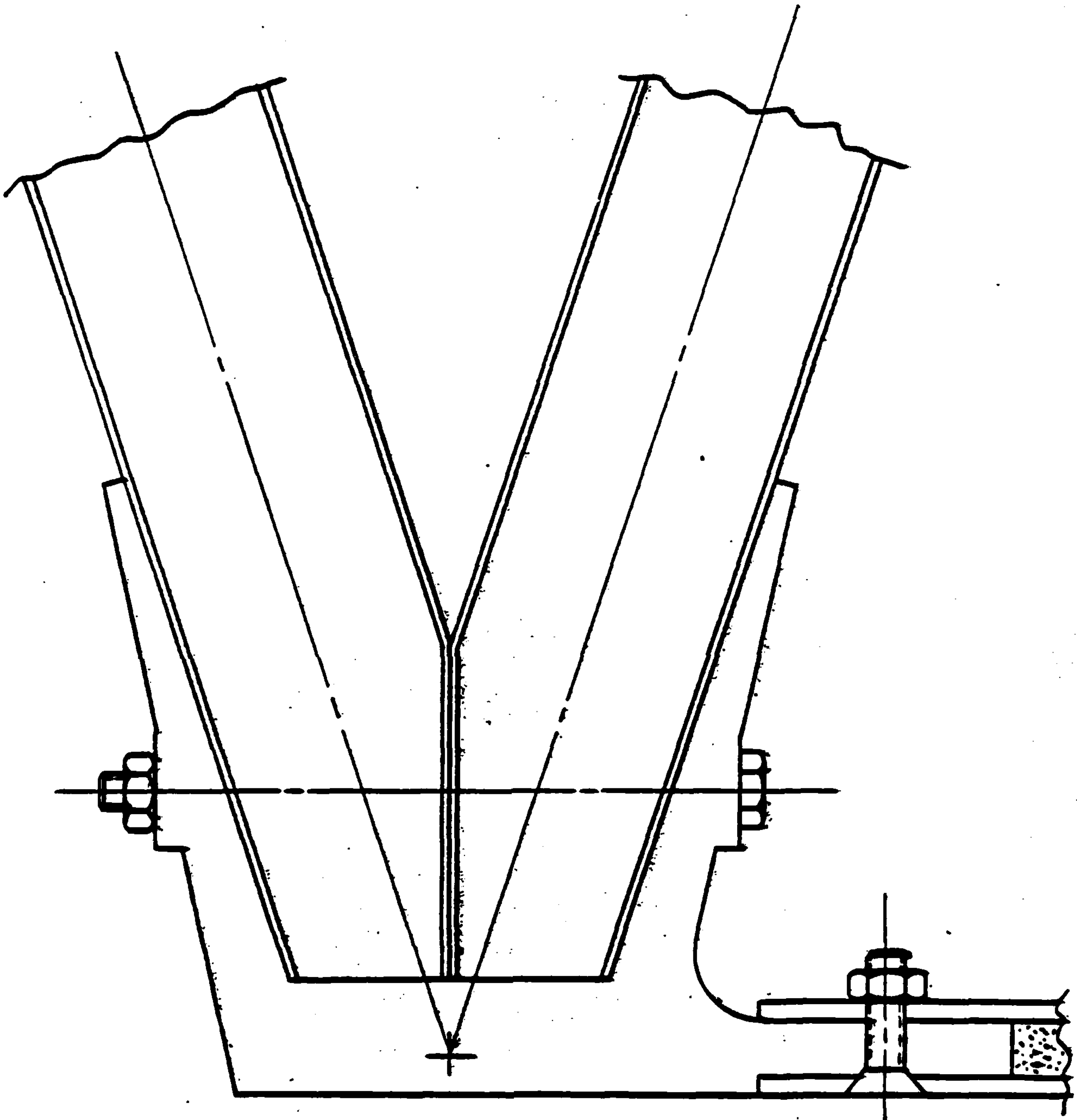


FIGURE V

DRAWN D. EREKSON	11/19/81	**FIBER SCIENCE, INC.** SALT LAKE CITY, UTAH 84116	
APPROVAL		TITLE LOWER CHORD/WEB JOINT	
APPROVAL		SIZE A CODE IDENT 32500	DWG NO: REV
RELEASE DATE		SCALE: 1/1 UNIT WT:	SHEET 12 OF

IV STRESS ANALYSIS

A. DESIGN CRITERIA

TEMPERATURE ~ -30 °F TO °F

HUMIDITY ~ 85 %

IMMERSION IN & SATURATED WITH WATER

WEB MODULE SHALL BE BUOYANT

LOADS

SHEAR = 82,000 LB (WEB & BULKHEAD)

COMPRESSION LOAD TOP CHORD

- CRITICAL TIRE LOAD ~ 100 PSI (20 K)
  8.33" × 24"
- CRITICAL AXLE LOAD ~ 100 PSI (25.5 K)
  7.08" × 18" – 5" – 7.08" × 18"
- CRITICAL TRACK LOAD ~ 12.55 PSI (70 K)
  180" × 31"

COMPRESSIVE LOAD BOTTOM CHORD

- 82,000 LB EVENLY DISTRIBUTED 1 M × WIDTH OF CHORD
- ROLLER LOAD ~ 36,170 LB AL ROLLER 6" WIDE & 16" DIA.

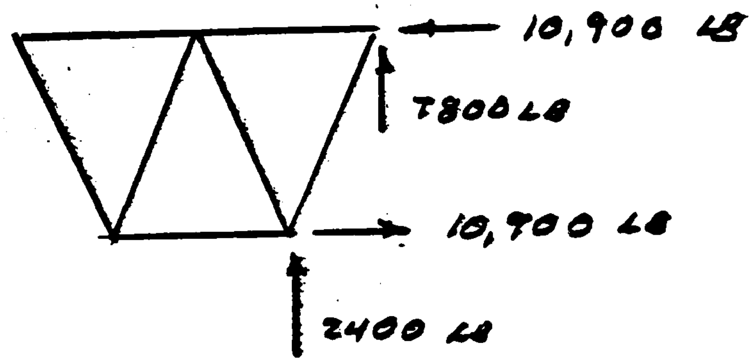
BEAM BENDING LOADS

M = 2163,000. FT-LB

M = -1009,000. FT-LB

NOTE – APPLY MOST CRITICAL COMPRESSIVE LOAD WITH SHEAR LOAD

CROSS BRACE PIN LOADS



FACTORS OF SAFETY

FS = 1.5 ON ULT. STRENGTH

FS = 1.33 ON YIELD STRENGTH

FS = 1.5 ON BUCKLING

B. FAILURE CRITERION REF ~ HILL - VON MISES

$$\left(\frac{\sigma_x}{F_x}\right)^2 + \left(\frac{\sigma_y}{F_y}\right)^2 - \left(\frac{\sigma_x \sigma_y}{F_x F_y}\right) + \left(\frac{\tau}{F_{xy}}\right)^2 = 1$$

$$\left(\frac{\sigma_x}{F_x}\right) = 1$$

$$\left(\frac{\sigma_y}{F_y}\right) = 1$$

C. BUCKLING CRITERION REF ~ NACA TN 3781

$$R_x + R_y = 1$$

$$R_c + R_s^2 = 1$$

D. MATERIALS

FIBER PROPERTY SUMMARY

PROPERTY	E-GLASS	S2-GLASS	T-300	HMS
$E_{\parallel}$, 10^6 PSI	10.5	12.6	33.2	50.0
$E_{\perp}$, 10^6 PSI	10.5	12.6	2.8	1.4
G, 10^6 PSI	.4	.4	2.0	2.0
F_{tu}, 10^3 PSI	260	325	360	300
F_{cu}, 10^3 PSI	220	325	300	250
$\alpha_{\parallel}$, 10^{-6} °F	2.8	3.1	−0.3	−0.3
$\alpha_{\perp}$, 10^{-6} °F	2.8	3.1	4.0	4.0
ρ, LB/IN^3	.092	.090	.063	.066

RESIN PROPERTY SUMMARY

EPON 826 / TONOX LC 31 PHR

$E = 0.37 \times 10^6$ PSI

$\mu = .35$

$F_{tu} = 10,100$ PSI

$F_{su} = 9000$ PSI

$\alpha \approx 40 \times 10^{-6}$ °F

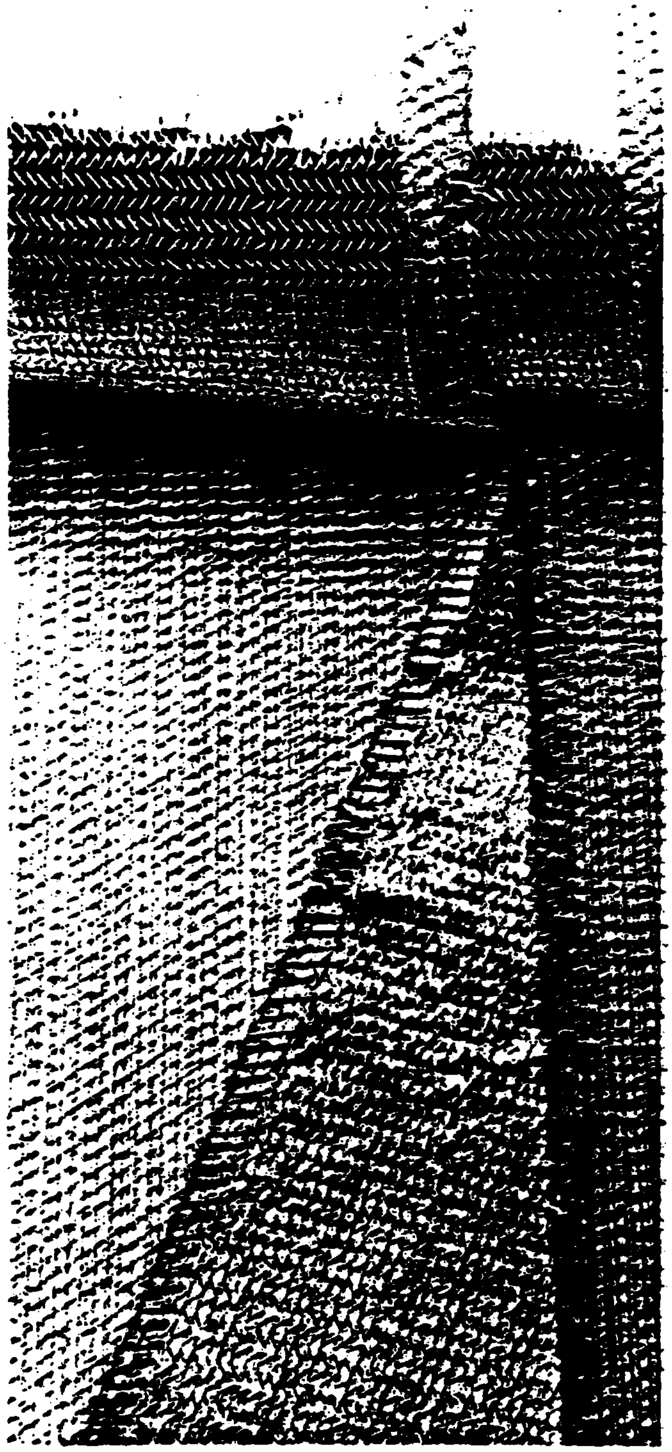
$\rho = .043$ LB/IN^3

CURE ~ 2 HR @ 175 °F + 3 HR @ 300 °F

KNYTEX CDB

A Revolutionary "Triaxial" Fabric

Our CDB fabric is a unique concept in reinforcing material. A new "triaxial" fabric which combines the most desirable characteristics of both unidirectional and double bias concepts. Triaxial design provides improved strength in three directions, giving you isotropic reinforcements, with unidirectional strength.



Knytex CDB has exceptionally high tensile strength and, because of our unique knitting process, is especially useful where torque loading is a critical factor.

This fabric is a new breakthrough with tremendous potential for innovative use in the automotive industry. It has already proven it's worth in marine hull design and the manufacture of wind turbine blades, where strength and weight are important factors.

Knytex CDB triaxial fabric, a proven innovation for the future . . . today!

PRODUCT INFORMATION

Our new CDB triaxial fabric is nonwoven, adding to its tremendous versatility and improving overall mechanical strength.

A revolution in nonwoven fabrics, the triaxial construction provides strength in three directions: 0 degrees, 45 degrees, and 135 degrees. Traditional nonwoven fabrics are limited to only 0 and 90 degree reinforcement capabilities.

A fabric of tomorrow, CDB presents unlimited applications. Its exceptional torque strength and primary strength in the warp direction make it possible to meet the growing demands of the plastics industry for some time to come.

The Knytex CDB triaxial fabric is available with "E" glass roving, but other yarns such as "S" glass, Kevlar, and Graphite could be used. The unique construction process provides 50 percent of the fabric weight in the direction of the warp, with 25 percent in each of the 45 degree directions.

Physical Data — CDB 340:
Widths: 3 inches to 50 inches
Weight: 34 ounces per sq. yard
Thickness: .050 inches

Mechanical Properties — CDB 340:
The mechanical properties shown in the table were made with 4-ply CDB 340 and a general purpose polyester resin. Total thickness of the laminate was .158 inches and the fabric to resin ratio as measured was 50:50 by weight. Materials were tested in accordance with ASTM methods D-695, D-790, and D-638.

	Warp	45° Right Bias	45° Left Bias
Compressive strength (psi)	57,400	40,600	49,600
Compressive Modulus (psi) $X10^{6}$	2.2	1.5	2.2
Tensile strength (psi)	66,200	30,500	35,600
Tensile Modulus (psi) $X10^{6}$	3	1.5	1.6
Flexural strength (psi)	100,900	57,300	66,400
Flexural Modulus (psi) $X10^{6}$	2.9	2.3	2.3

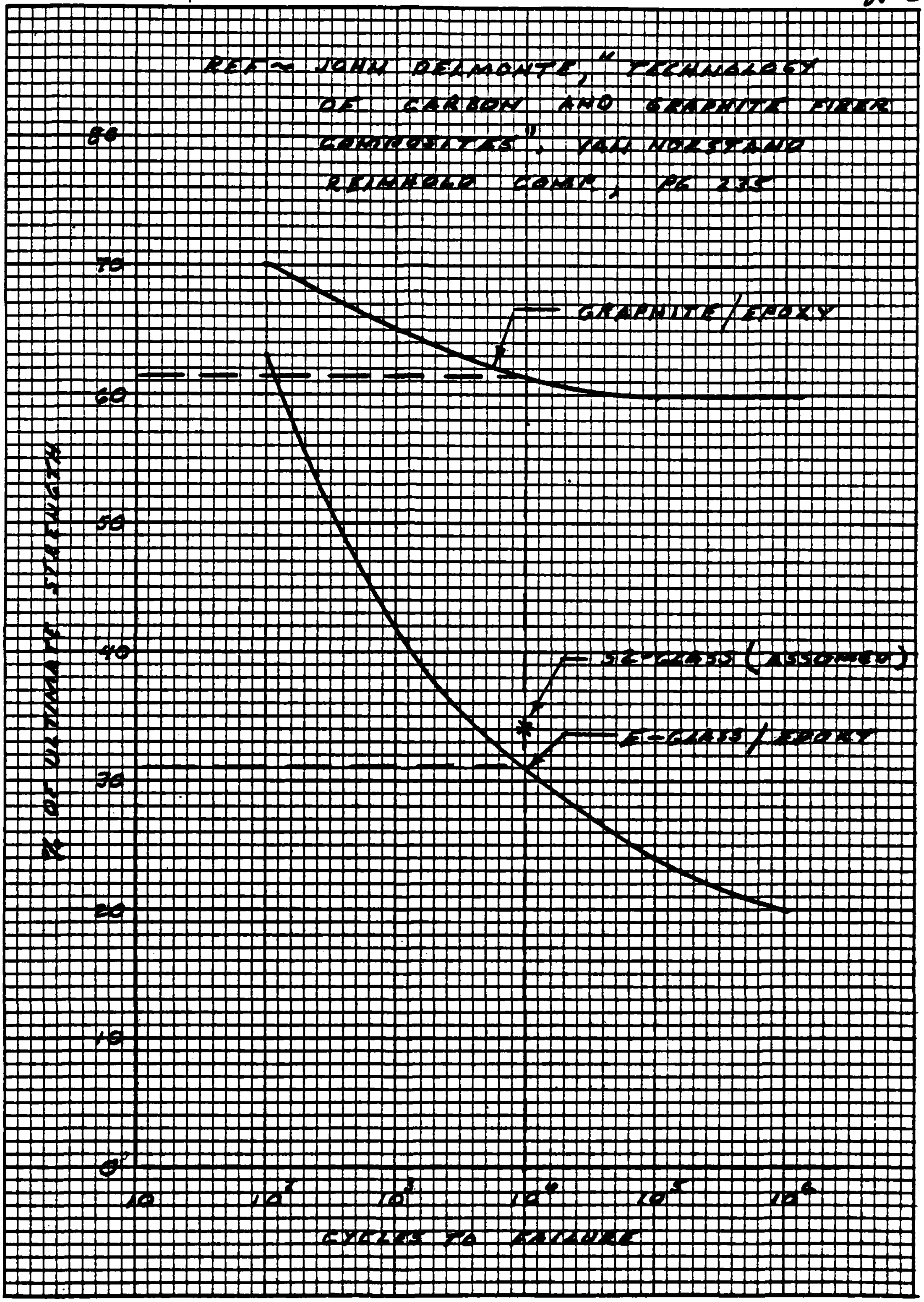
Sales Office:
201 Executive Office Park • 4600 W. Illinois • Midland, Texas 79703
Mailing Address: P.O. Box 5293 • Midland, Texas 79701
Phone: (915) 694-0912

Skip Hamilton
Mkt Mgr

Plant:
Highway 46N • Seguin, Texas 78155
Mailing Address: P.O. Box 1046 • Seguin, Texas 78155
Phone: (512) 379-0830

George [illegible] (Knytex LA)
213-266-0131

10-15-81
JPA



REF ~ JOHN DELMONTE, "TECHNOLOGY OF CARBON AND GRAPHITE FIBER COMPOSITES", VAN NOSTRAND REINHOLD COMP., PG 235
80
70
60
50
40
30
20
10
0
% OF ULTIMATE STRENGTH
GRAPHITE/EPOXY
S2-GLASS (ASSUMED)
E-GLASS/EPOXY
10
10^2
10^3
10^4
10^5
10^6
CYCLES TO FAILURE

10-15-81
JPL

CORE PROPERTY SUMMARY

PROPERTY	WR II [1]	HRH-10 [2]	CR III [3]	PVC [4]	URETHANE [5]	ACG-3/8 [6]
E_c, 10^3 PSI	55	28	86	6.5	5.4	92
G_L, 10^3 PSI	19	7.5	55	2.2	3.0	40
G_W, 10^3 PSI	9	3.5	23	2.2	3.0	20
F_c, PSI	570	360	200	200	180	325
F_{SL}, PSI	255	200	230	120	180	95
F_{SW}, PSI	175	95	143	120	125	55
ρ, LB/FT^3	3.8	4.0	3.5	6.2	6.0	3.6
ρ, LB/IN^3	.00220	.00231	.00203	.00359	.00347	.0020

1- WR II -3/8-3.8
2- HRH-1/4-4.0 $\Big\}$ HEXCEL
3- 3/16-2024-.0015
4- KLEGECELL
5- GENERAL PLASTICS MFG CO. LAST-A-FOAM
6- ACG-3/8-3.6 HEXCEL

COMPOSITE PROPERTY SUMMARY, 45% @ 90°, 55% @ ±45°

PROPERTY	E-GLASS	S2-GLASS	T-300	HMS	E & T300*	S2 & T300*	E & HMS*	S2 & HMS*
E_x, 10^6 PSI	1.522	1.658	2.650	3.395	1.548	1.663	1.473	1.598
E_y, 10^6 PSI	3.019	3.516	8.471	12.26	8.104	8.122	11.87	11.88
G_{xy}, 10^6 PSI	.9627	1.109	2.561	3.676	1.030	1.177	1.030	1.117
μ_{xy}	.3017	.2938	.2376	.2317	.1213	.1562	.0824	.0933
μ_{yx}	.5985	.6262	.7576	.8365	.6350	.6651	.6689	.6935
F_{xGU}, PSI	17,928	25,051	29,266	20,904	8353	9469	4689	5338
F_{yGU}, PSI	63,860	90,812	94,128	72,824	73,576	73,808	59,624	59,753
F_{xyU}, PSI	22,415	29,978	32,797	25,885	15,253	16,876	8930	8832
α_x, 10^{-6} IN	7.091	9.084	6.071	5.565	9.860	9.771	10.31	10.20
α_y, 10^{-6} IN	4.324	4.351	.2241	.3196	.4936	.4932	.2411	.2407
ρ, LB/IN^3	.0678	.0665	.0530	.0545	.0610	.0604	.0616	.0611
FATIGUE	.31	.34	.615	.615	.615	.615	.615	.615
COST, $/LB								

* CARBON FIBERS @ 90° & GLASS FIBERS @ ±45°

STYLE 120 E-GLASS FABRIC / EPOXY

$t = 0.004$ IN / PLY

$W = 3.16$ OZ / YD^2

$$t_e = \frac{3.16}{16 \times 36^2 \times .092} = .00166 \text{ IN.}$$

$$V_f = \frac{.001666}{.004} = .4141$$

$$\rho_c = .4141 \times .092 + .5859 \times .043 = .0633 \text{ LB/IN}^3$$

WEIGHT PER IN^2 FOR TWO PLIES STYLE 120 E-GLASS FABRIC/EPOXY

$$W = 2 \times .004 \times .0633 = .00051 \text{ LB/IN}^2$$

HEXCEL

2024 ALUMINUM HONEYCOMB
D.S. 2200

March 6, 1981

CORROSION RESISTANT 2024 ALUMINUM HONEYCOMB

FEATURES:

Markedly Improves Corrosion Resistance
Maintains Corrosion Protection at Elevated Temperatures
Heat Treatable, High Strength Core Material
Highest Strength to Weight Ratio as a Sandwich Core
Strength Retention at Elevated Temperature

APPLICATIONS:

CR III® 2024 Aluminum Honeycomb has been made available by Hexcel for applications where high strength and strength retention for elevated temperature service are required. 2024 AL honeycomb material is available in either the high strength T81 temper or in the T3 condition which has more formability and can subsequently be heat treated to the T81 condition. The principal utilization of 2024 AL honeycomb is in high performance applications where service temperatures require long term stability to 350°F and short term service as high as 420°F.

SPECIFICATIONS:

All Corrosion Resistant 2024 expanded aluminum honeycomb materials meet the requirements of Military Specification MIL-C-7438 where applicable.

STANDARD DIMENSIONS:

CR III 2024 Aluminum Honeycomb materials are available in the following sizes:

Density	L	W
Less than 5.0 pcf	48" + 2 -0	96" + 4 -0
5.0 to 8.0 pcf	30" + 2 -0	96" + 4 -0
9.5 pcf	24" + 2 -0	54" + 4 -0

T dimensions have a minimum of 0.125" and a maximum of 10.0". Special L, W and T dimensions are available on request.

THICKNESS TOLERANCES:

Panel Thickness	Standard Tolerance
.125" to 4.000"	± .005" (except for 1/8 - .003 - 9.5)
4.001" and Over	± .062" (except for 1/8 - .003 - 9.5)

DENSITY TOLERANCES:

The nominal densities of 2024 Aluminum Honeycomb products are shown in Table I. Standard density tolerance on the nominal density is ± 10%.

® Registered Trademark, Hexcel

TYPE DESIGNATION:

Hexcel CR III 2024 Aluminum Honeycomb is designated as follows:

Mat'l. — Cell Size — Alloy — Temper — Foil Thickness — Density

EXAMPLE:

CR III—3/16—2024
T81—.0015N—3.5

WHERE:

CR III designates corrosion resistance aluminum honeycomb

3/16 is the cell size in inches.

2024 is the aluminum alloy used.

T81 is the temper condition.

.0015 is the nominal foil thickness in inches.

N indicates cell walls are not perforated. (Perforated core is not available.)

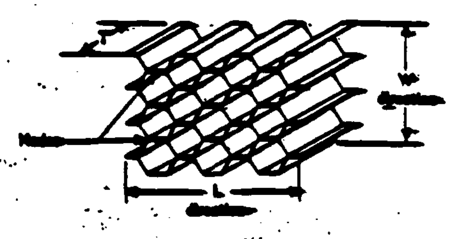
3.5 is the nominal density in pounds per cubic foot.

DIMENSIONAL NOMENCLATURE:

T=Thickness, or cell depth

L=Ribbon direction, or longitudinal direction.

W=Transverse direction, or direction perpendicular to the ribbon.



CUSTOM PROCESSING:

CR III 2024 Aluminum Honeycomb can be provided machined or formed to various shapes. This can include edge chamfering, simple and complex taper cuts, and other special machined configurations. Contact the nearest Hexcel Sales Office for additional information.

AVAILABILITY:

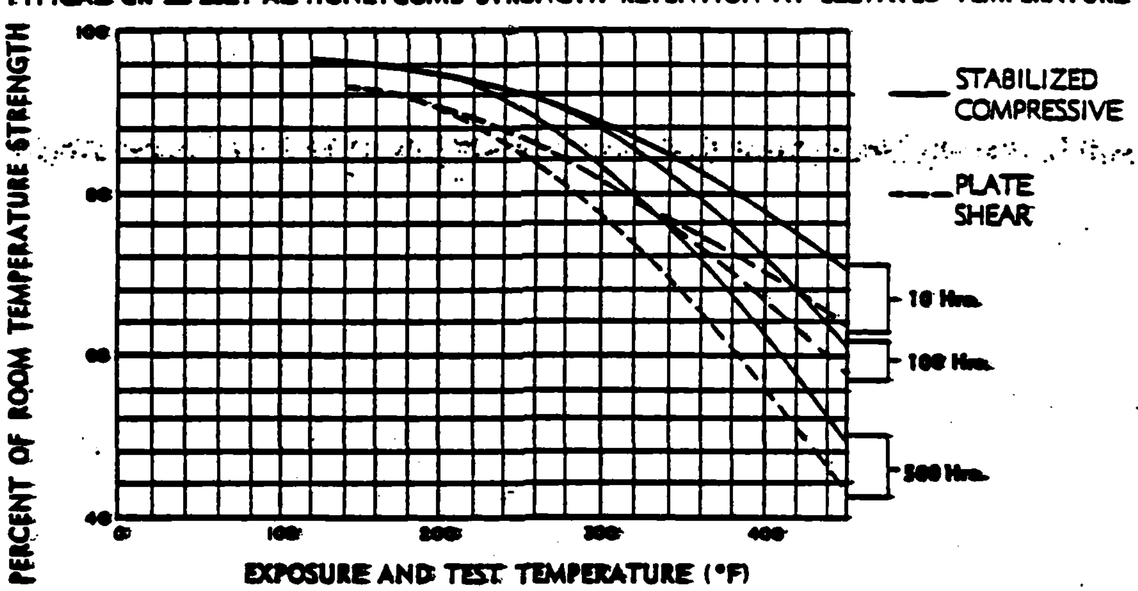
Standard size CR III 2024 Aluminum Honeycomb will be shipped F.O.B. Graham, Texas. Request for quotations should be forwarded to the nearest Hexcel Sales Office listed on this data sheet. Sales terms are 1% in 15 days from date of invoice, net due in 30 days, or 2% cash with order (CWO).

TABLE I **MECHANICAL PROPERTIES**

HEXCEL HONEYCOMB DESIGNATION Cell-Material-Gage	Nominal Density pcf	COMPRESSIVE					Crush Strength psi	PLATE SHEAR					
		Bare		Stabilized				"L" Direction			"W" Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
		typ	min	typ	min	typical	typ	typ	min	typical	typ	min	typical
1/8-2024-.0015	5.0	700	525	780	620	200	425	500	400	82.0	315	250	33.0
1/8-2024-.0020	6.7	1100	825	1225	980	300	640	760	600	118	470	375	45.0
1/8-2024-.0025	8.0	1480	1100	1650	1320	380	840	960	770	148	590	470	54.0
* 1/8-2024-.0030	9.5	1970	1475	2300	1725	480	1120	1150	950	170	650	585	64.0
3/16-2024-.0015	3.5	330	250	370	290	86	200	290	230	55.0	180	143	23.0
1/4-2024-.0015	2.8	220	165	250	175	40	110	200	140	42.0	120	88	19.0

* Not available with a CR III finish, but can be supplied with R-500 corrosion primer.

TYPICAL CR III 2024 AL HONEYCOMB STRENGTH RETENTION AT ELEVATED TEMPERATURE



ADMINISTRATIVE OFFICES:
Dublin, California 94566, 11711 Dublin Boulevard, (415) 828-4200

SALES OFFICES:
Arlington, Texas 76011, Suite 105, 2710 Avenue E East, (817) 274-2578
Bel Air, Maryland 21014, Loyola Federal Bldg., Main St. and Fulford Ave., (301) 838-0050
Bellevue, Washington 98004, Suite 301, "400" Bldg., 400 - 108th Ave., N.E., (206) 455-0418
Dublin, California 94566, 11711 Dublin Boulevard, (415) 828-4200
Long Beach, California 90807, Suite 622, 3711 Long Beach Blvd., (213) 595-6811

HEXCEL

Hexcel S.A. - Rue Trois Bourdons, Welkenraedt, Liege, Belgium, 087-880765

WR II® SHELTER CORE®
WATER RESISTANT
KRAFT HONEYCOMB
D.S. 1040
March 31, 1981

WR II® SHELTER CORE®

WATER RESISTANT STRUCTURAL KRAFT HONEYCOMB

FEATURES:

Low Cost
High Structural Strength/Low Weight
High Resistance to Water Migration
High Fungus Resistance
Structural Grade Honeycomb

APPLICATIONS:

WR II Shelter Core has been developed by Hexcel as a structural grade honeycomb core material for use in the construction of various types of air-transportable military shelters. The product meets the requirements of militray specification MIL-H-21040, C revision, and has substantially less than one cell water migration in 24 hours when tested to MIL STD. 401B.

Typical applications include personnel shelters, transportable medical units, electronic enclosures, utility buildings and intermodal cargo containers.

DESCRIPTION:

WR II Shelter Core is a highly water resistant core material produced from kraft cellulose fiber web materials under a patented Hexcel process. The honeycomb web has been treated with special chemicals and polymers to provide anti-water migration characteristics and excellent mechanical properties.

Shelter Core can be bonded with basic adhesive systems to any standard sandwich facing material to provide a high strength, low cost sandwich panel. Due to moisture pick-up, WR II core may have to be oven dried before bonding.

SPECIAL PRODUCTS:

WR II Shelter Core can be provided pre-cut to specific L and W dimensions, as well as in expanded block form up to 30 inches T. Panels up to 4 inch T can also be supplied filled with a 2.0 pcf polyurethane foam for added thermal insulation. In addition, bare or foam filled core is available with HEXABOND® cell edge adhesive eliminating the need for tape or paste adhesive in bonding flat sandwich panels. For information on these special products contact your nearest Hexcel Sales Office.

® Registered Trademark, Hexcel.

TYPE DESIGNATION:

WR II Shelter Core Honeycomb is designated as follows:

Material — Cell Size — Density

Example:

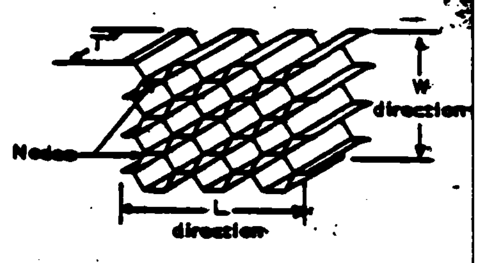
WR II-3/8-3.8

Where:

WR II designates honeycomb type
3/8 is the cell size in inches
3.8 is the nominal density in pounds per cubic foot

DIMENSIONAL NOMENCLATURE

T Thickness, or cell depth
L Ribbon direction, or width
W Long direction, or direction perpendicular to the ribbon



AVAILABILITY:

WR II Shelter Core will be supplied F.O.B. Casa Grande, Arizona. Check with your local Hexcel Sales Office for availability.

SPECIFICATIONS:

General — WR II Shelter Core will be supplied in flat expanded sheets free from foreign contaminates and ready for bonding.

Configuration — The average cell size as measured across the flats (nodes) of cells will be ± 10% of the nominal. Cell determination will be made by measuring the length of 10 consecutive cells in 6 random locations and averaging the results. Double laps will be permitted as long as the core blankets are within density tolerance. Unbonded nodes will be permitted to the extent that no opening larger than three times the nominal cell size is created and the minimum mechanical properties are obtainable.

Density — The acceptable tolerance on density will be ± 10%.

Water Migration — The WR II Shelter Core product line will meet a limit of 1 cell water migration in 24 hours when tested in accordance with MIL. STD. 401B.

Standard Dimensions — WR II Shelter Core materials are available in the following standard sizes and dimensions with tolerances indicated:

PRODUCT	L	W	T Max.	T Min.
WR II - 3/8 - 2.5	45" Min.	96" Min.	30"	0.250"
WR II - 3/8 - 3.8	45" Min.	96" Min.	30"	0.250"

Thickness tolerance for up to 4.000" T will be ± .010, for over 4.000" T tolerance will be ± .125". Other L and W dimensions are available. Please contact your nearest Hexcel Sales Office for additional information.

Mechanical Properties — WR II Shelter Core meets the mechanical property requirements of MIL-H-21040 revision C. In addition, the following typical properties have been obtained when tested per MIL-STD-401B at 0.500 inch T.

HEXCEL HONEYCOMB DESIGNATION	COMPRESSIVE			PLATE SHEAR			
	Bare	Stabilized		"L" Direction		"W" Direction	
Material - Cell - Density	Strength psi	Strength psi	Modulus ksi	Strength psi	Modulus ksi	Strength psi	Modulus ksi
WR II - 3/8 - 2.5	260	340	33	170	13	100	7
WR II - 3/8 - 3.8	515	570	55	255	19	175	9

Typical Bare Compressive Strength Retention after 24 hour soak in distilled water is 55%.

FOR INDUSTRIAL USE ONLY — In determining whether the material is suitable for a particular application, such factors as overall product design and the processing and environmental conditions to which it will be subjected should be considered by the user. The following is made in lieu of all warranties, express or implied. Seller's only obligation shall be to replace such quantity of this product which has proven to not substantially comply with the data presented in this bulletin. In the event of the discovery of a non-conforming product, Seller shall not be liable for any commercial loss or damage, direct or consequential, arising out of the use of or the inability to use the product. Before using user shall determine the suitability of the product for his intended use, and user assumes all risks and liability whatsoever in connection therewith. Statements relating to possible use of our product are not guarantees that such use is free of patent infringement or that they are approved for such use by any government agency. The foregoing may not be changed except by an agreement signed by an officer of seller.

HEXCEL

ADMINISTRATIVE OFFICES:
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SALES OFFICES:
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Bel Air, Maryland 21014, Loyola Federal Bldg., Main St. and Fulford Ave., (301) 838-0050
Bellevue, Washington 98004, Suite 301, "400" Bldg., 400 - 108th Ave., N.E., (206) 455-0418
Dublin, California 94566, 11711 Dublin Boulevard, (415) 828-4200
Long Beach, California 90807, Suite 622, 3711 Long Beach Blvd., (213) 595-6811

Hexcel S.A. - Rue Trois Bourdons, Welkenraedt; Liege, Belgium, 087-880765

HEXCEL®

ACG® — HONEYCOMB
ALUMINUM COMMERCIAL GRADE
D.S. 6000
Feb. 14, 1980

ACG® — ALUMINUM COMMERCIAL GRADE HONEYCOMB

FEATURES:

Low Cost
High Structural Strength/Low Weight
Corrosion Resistant

APPLICATIONS:

ACG is a commercial honeycomb core offering industrial designers, at relatively low cost, the advantages of an all-metal honeycomb with long service life and resistance to fungus, moisture and temperature. Uses include industrial tooling panels, architectural panels, shelving, storage tank covers, building walls, table and counter tops.

DESCRIPTION:

Aluminum commercial grade honeycomb is made from 3000 series aluminum alloy foil approximately 3 mils thick. An organic coating is applied to the foil which provides excellent protection to corrosive atmospheres. Four cell sizes and densities are available. The honeycomb is manufactured by bonding together sheets of aluminum foil which are expanded to form a cellular honeycomb configuration. The node bond adhesive is a thermosetting type; cured under heat and pressure with the honeycomb in the unexpanded or HOBE® (HOneycomb Before Expansion) condition. Slices are cut from the unexpanded material to specified thickness, or cell depth, and then expanded to final configuration.

The honeycomb can be supplied either expanded or in HOBE slices. Any panel thickness between 0.125 and 20 inches can be provided. Material will normally be perforated such that all cells will be vented in a slice as thin as 0.187 inches. Non-perforated honeycomb is available upon request.

SPECIAL PRODUCTS/CUSTOM PROCESSING:

Aluminum commercial grade honeycomb can be provided machined or formed into various shapes. This can include edge chamfering, simple and complex taper cuts, and other special machined configurations. Hexcel can also supply flat sandwich panels using ACG with a wide variety of facing materials, close-outs and dimensions. Contact the nearest Hexcel Sales Office for additional information.

® Registered Trademark, Hexcel

TYPE DESIGNATION:

ACG honeycomb is designated as follows:

Material — Cell Size — Density — Perforated

Example:

ACG - 3/8 - 3.6P

Where:

ACG designates corrosion resistant honeycomb type

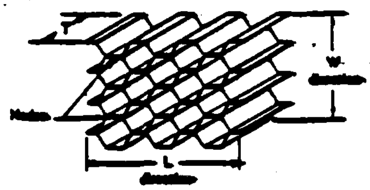
3/8 is the cell size in inches

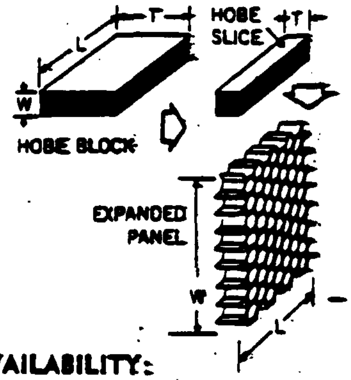
3.6 is the nominal density in pounds per cubic foot.

P—Indicates cells walls are perforated.

DIMENSIONAL NOMENCLATURE

T=Thickness, or cell depth
L=Ribbon direction, or width
W=Long direction, or direction perpendicular to the ribbon





AVAILABILITY:

ACG honeycomb will be supplied F.O.B. Graham, Texas, or Casa Grande, Arizona. Contact nearest Hexcel Sales Office for delivery information.

Standard Dimension:

Hexcel's aluminum commercial grade materials are available in the following standard size:

Unexpanded L (HOBE):	Expanded Dimensions:	Sq. Ft. / Per Panel:
66" ± 1"	48" + 2" — 0" L x 102" + 2" — 6" W	34

One of the major advantages of the ACG product line is the availability of a structural metallic honeycomb at low cost. This is possible because the product is made in only one panel size and is shipped untrimmed as expanded. While variations in "T" are available, the "L" and "W" dimensions will only be supplied in the expanded dimensions shown above. Special "L" and "W" requirements or pieces cut to size can be supplied upon request but may carry a premium charge, depending on volume.

Thickness Tolerance:

Tolerance on cut thickness are as follows:

Panel Thickness	Standard Tolerance
.125 to 4.000"	± .008"
4.001" and Over	± .062"

Density Tolerance:

The standard density tolerance on the nominal density is ± 15%.

Mechanical Properties: TABLE I

ACG honeycomb has been tested per MIL Std. 401. The following typical properties apply:

HEXCEL HONEYCOMB DESIGNATION Material-Cell-Gage	Nominal Density pcf	COMPRESSIVE			Crush Strength psi	PLATE SHEAR			
		Bare	Stabilized			"L" Direction		"W" Direction	
		Strength psi	Strength psi	Modulus ksi		Strength psi	Modulus ksi	Strength psi	Modulus ksi
		typ.	typ.	typ.	typ.	typ.	typ.	typ.	typ.
ACG 1/4-.002	5.2	595	410	148	245	345	63	215	31
ACG 3/8-.002	2.6	325	340	92	128	210	40	130	20
ACG 3/4-.002	1.8	95	110	24	45	95	16	55	8
ACG 1-.002	1.4	60p	65p	16p	25	55p	14p	40p	7p

Tested at 0.625 inch thickness. p — prelminary values

FOR INDUSTRIAL USE ONLY

The following is made in lieu of all warranties, express or implied: Seller's only obligation shall be to replace such quantity of this product which has proven to not substantially comply with the data presented in this bulletin. In the event of the discovery of a non-conforming product, Seller shall not be liable for any commercial loss or damage, direct or consequential, arising out of the use of or the inability to use the product. Before using user shall determine the suitability of the product for his intended use, and user assumes all risks and liability whatsoever in connection therewith. Statements relating to possible use of our product are not guarantees that such use is free of patent infringement or that they are approved for such use by any government agency. The foregoing may not be changed except by an agreement signed by an officer of seller.

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HRH-10 NYLON FIBER REINFORCED HONEYCOMB

HEXCEL HONEYCOMB DESIGNATION	COMPRESSIVE					PLATE SHEAR					
	Bare		Stabilized			"L" Direction			"W" Direction		
Material - Cell - Density Gage	Strength psi		Strength psi		Modulus ksi	Strength psi		Modulus ksi	Strength psi		Modulus ksi
Hexagonal	typ	min	typ	min	typical	typ	min	typical	typ	min	typical
HRH 10 - 1/8 - 1.8 (1.5)	110	70	130	85	—	90	65	3.7	50	36	2.0
HRH 10 - 1/8 - 3.0 (2)	300	180	330	270	20	180	162	7.0	95	85	3.5
HRH 10 - 1/8 - 4.0 (2)	500	330	560	470	28	245	225	9.2	140	110	4.7
HRH 10 - 1/8 - 5.0 (3)	775	600	860	660	—	325	235	—	175	120	—
HRH 10 - 1/8 - 6.0 (3)	1075	800	1125	825	60	370	260	13.0	200	135	6.0
HRH 10 - 1/8 - 8.0 (3)	1575	1100	1700	1250	78	490	355	16.0	250	190	7.8
HRH 10 - 1/8 - 9.0 (3)	1700	1400	1800	1600	90	520	370	17.0	270	240	9.0
HRH 10 - 5/32 - 5.0 (4)	800p	—	900p	—	—	360p	—	11.5p	180p	—	5.0p
HRH 10 - 5/32 - 9.0 (4)	1775p	—	2050p	—	—	525p	—	18.0p	285p	—	9.5p
HRH 10 - 3/16 - 2.0 (2)	150	90	170	105	11	110	72	4.2	55	40	2.2
HRH 10 - 3/16 - 3.0 (2)	300	180	330	270	20	150	130	5.0	95	67	3.5
HRH 10 - 3/16 - 4.0 (3)	500	320	560	470	28	245	215	7.8	140	110	4.7
HRH 10 - 3/16 - 4.5 (5)	425	320	475	400	—	290	225	9.5	145	110	4.0
HRH 10 - 3/16 - 6.0 (5)	650	580	700	650	—	390	330	14.5	185	150	6.0
HRH 10 - 1/4 - 1.5 (2)	90	45	95	55	6	75	45	3.0	35	23	1.5
HRH 10 - 1/4 - 2.0 (2)	150	80	170	105	11	110	72	4.2	55	36	2.8
HRH 10 - 1/4 - 3.1 (5)	275	180	285	240	—	170	135	7.0	85	60	3.0
HRH 10 - 1/4 - 4.0 (5)	370	310	400	360	—	240	200	7.5	125	95	3.5
HRH 10 - 3/8 - 1.5 (2)	90	45	95	55	6	75	45	3.0	35	23	1.5
HRH 10 - 3/8 - 2.0 (2)	150	80	170	105	11	110	72	4.2	55	36	2.2
HRH 10 - 3/8 - 3.0 (5)	285p	—	300p	—	17p	170p	—	5.6p	95p	—	3.0p
OX-CORE											
HRH 10/OX - 3/16 - 1.8 (2)	110	70	130	—	—	60	45	2.0	60	35	3.0
HRH 10/OX - 3/16 - 3.0 (2)	365	250	400	270	17	115	95	3.0	125	95	6.0
HRH 10/OX - 1/4 - 3.0 (2)	350	210	385	250	17	110	90	3.0	115	90	6.0
FLEX-CORE											
HRH 10/F35 - 2.5 (3)	150	105	170p	119p	12p	70	49	4.0p	40	28	1.9p
HRH 10/F35 - 3.5 (5)	300p	—	350p	—	24p	150p	—	5.7p	80p	—	2.8p
HRH 10/F35 - 4.5 (5)	450p	—	490p	—	33p	270p	—	7.3p	150p	—	3.7p
HRH 10/F50 - 2.5 (3)	300	189p	350	217	24	150	105	5.7p	80	56	2.8p
HRH 10/F50 - 4.5 (5)	450p	—	490p	—	33p	270p	—	7.3p	150p	—	3.7p
HRH 10/F50 - 5.0 (5)	550	—	625	525	37	330	300	8.0	190	160	4.1
HRH 10/F50 - 5.5 (5)	650p	—	700p	—	42p	390p	—	8.8p	235p	—	4.6p

Test data obtained at 0.500 inch thickness.
p — preliminary properties (see page 11)

7075-T73 AL. (SHEET & PLATE)

		L.T.
F_{tu} =	67,000 PSI	67,000 PSI
F_{ty} =	56,000 PSI	56,000 PSI
F_{cy} =	55,000 PSI	58,000 PSI
F_{su} =	38,000 PSI	
F_{bru} =	105,000 PSI	($e/d = 1.5$)
F_{bru} =	134,000 PSI	($e/d = 2.0$)
F_{bry} =	84,000 PSI	($e/d = 1.5$)
F_{bry} =	102,000 PSI	($e/d = 2.0$)

$E_t = 10.3 \times 10^6$ PSI

$E_c = 10.6 \times 10^6$ PSI

$G = 3.9 \times 10^6$ PSI

$\mu = .33$

$\rho = .101$ LB/IN^3

$\alpha = 12.9 \times 10^{-6}$ °F

7005-T53 AL. EXTRUSION

		L.T.
F_{TU} =	50,000 PSI	48,000 PSI
F_{TY} =	44,000 PSI	42,000 PSI
F_{CY} =	43,000 PSI	44,000 PSI
F_{SU} =	28,000 PSI	
F_{bru} =	72,000 PSI	(e/d = 1.5)
F_{bru} =	95,000 PSI	(e/d = 2.0)
F_{bry} =	59,000 PSI	(e/d = 1.5)
F_{bry} =	73,000 PSI	(e/d = 2.0)
E_t =	10.3×10^6 PSI	
E_c =	10.5×10^6 PSI	
G =	3.9×10^6 PSI	
ρ =	.101 LB/IN^3	
α =	13.2×10^{-6} °F	
e =	10 %	

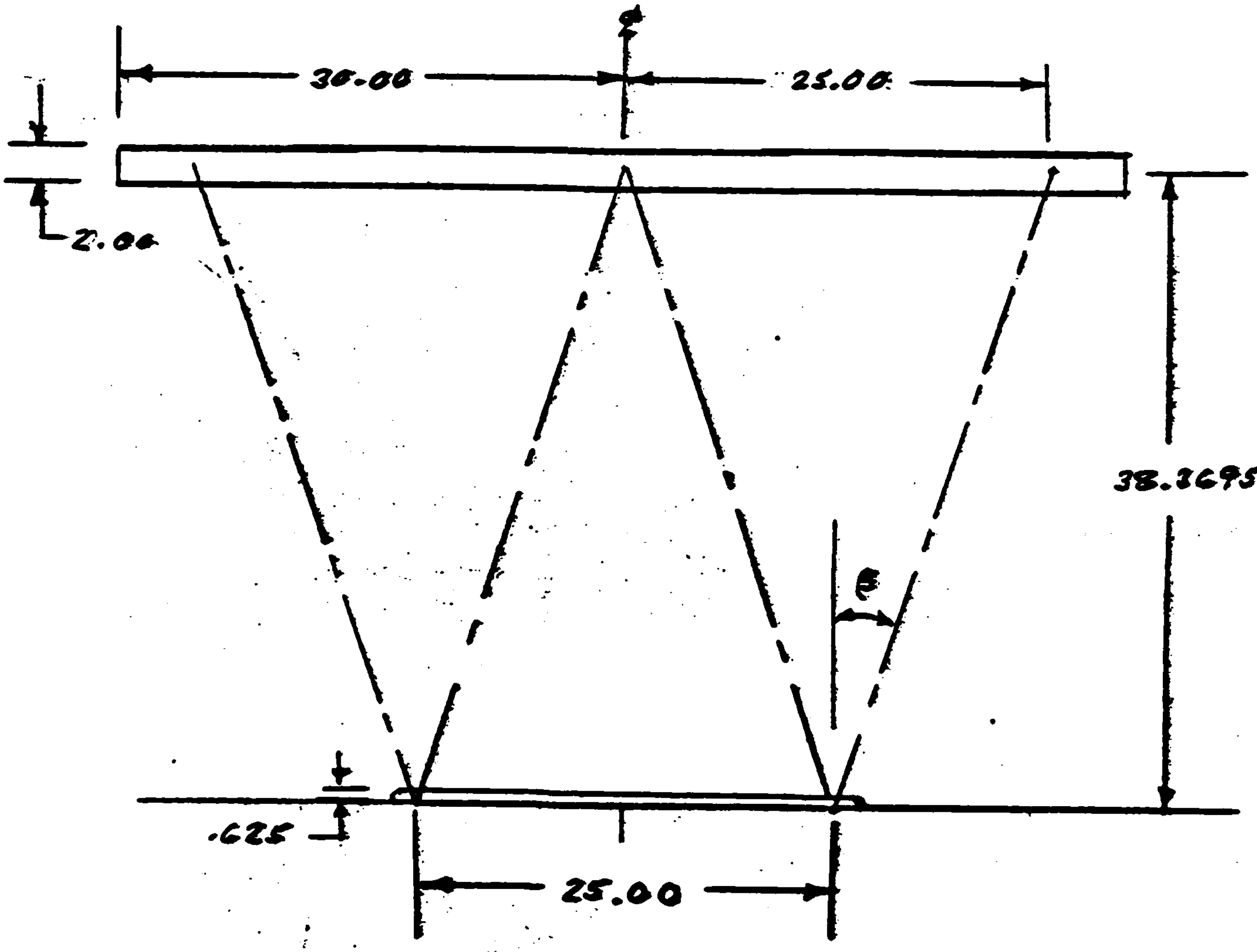
$$\mu = \frac{10.3 \times 10^6}{2 \times 3.9 \times 10^6} - 1 = .3205$$

SUPPLIERS ~ ALCOA
REYNOLDS
MARTIN MARIETTA

E. LOADING CALCULATIONS

STRUCTURAL ANALYSIS

THE WEB COMPRESSION AND SHEAR FLOW ARE CALCULATED FOR THE GEOMETRY SHOWN BELOW AS FOLLOWS,

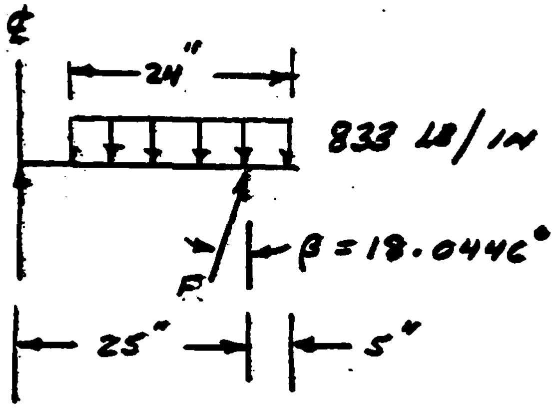


$$\beta = TAN^{-1}\left(\frac{35.00}{2 \times 38.3695}\right) = 18.0446 \text{ DEG.}$$

THE COMPRESSION LOAD ON THE WEB IS,

CRITICAL TIRE LOAD COND.

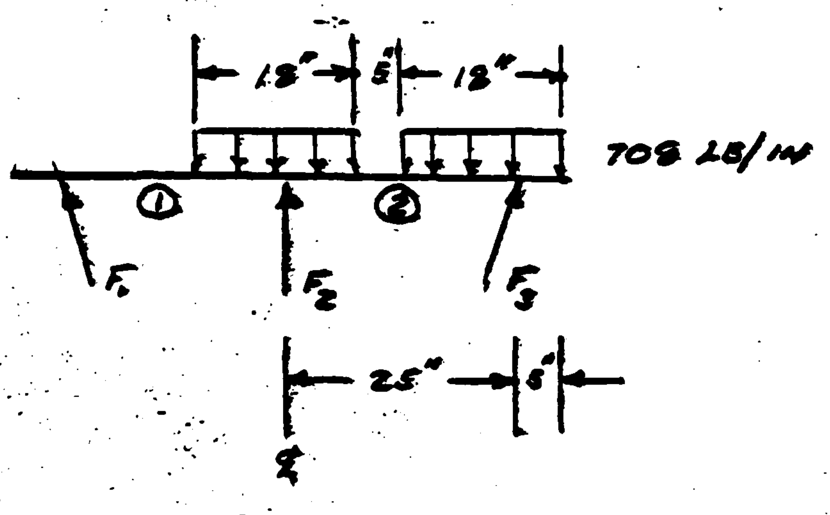
$$F = \frac{24 \times 833 \times 18}{25 \cos \beta} = 15{,}139 \text{ LB}$$



ESTIMATE 10" ARE EFFECTIVE

F = 1514 LB/IN.

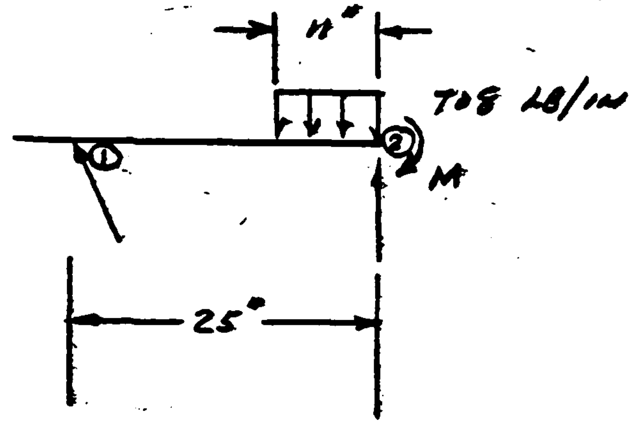
CRITICAL AXIAL LOAD COND.



THE REACTIONS WILL BE CALCULATED BY FREE BODYING THE BEAM AT REACTION POINT 2 & SOLVING FOR THE UNKNOWN MOMENT BETWEEN BEAMS BY EQUATING ROTATIONS AT PT 2.

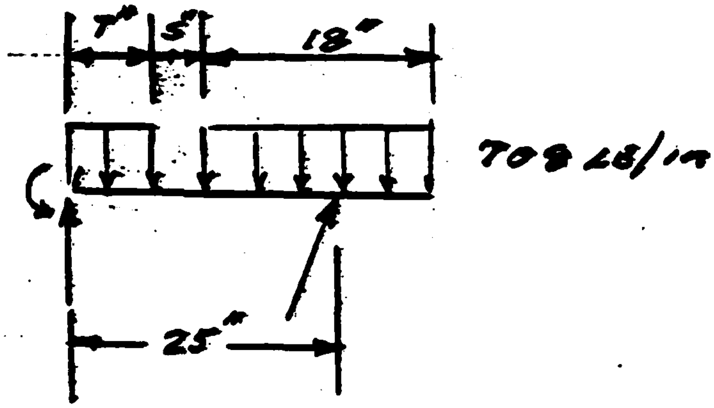
10-16-87
JPR

ROTATION AT THE RIGHT SIDE OF BEAM NO. 1 IS; (CRITICAL AXIAL LOAD COND.)



$$\theta_2 = \frac{207,300}{EI} - \frac{8.333\ M}{EI}$$

ROTATION AT LEFT SIDE OF BEAM NO 2 IS,



$$\theta_2 = \frac{-285,625}{EI} + \frac{8.333\ M}{EI}$$

EQUATING ROTATIONS & SOLVING FOR M

$$M = \frac{285,625 + 207,300}{8.333 + 8.333} = 29,577 \text{ IN-LB}$$

10-16-81

(CRITICAL AXIAL LOAD COND.)

$$F_{1V} = \frac{708 \times 11.0 \times 5.5 - 29,577}{25.0} = 530.28 \text{ LB}$$

$$F_{2V} = \frac{708 \times 11.0 \times 19.5 + 29,577}{25.0}$$

$$+ \frac{708\left(7 \times 21.5 + 18 \times 4.0\right) + 29,577}{25.0} = 14,742 \text{ LB}$$

$$F_{3V} = \frac{708\left(7 \times 3.5 + 18 \times 21.0\right) - 29,577}{25.0} = \underline{10,215.72 \text{ LB}}$$

Σ 25,488 LB

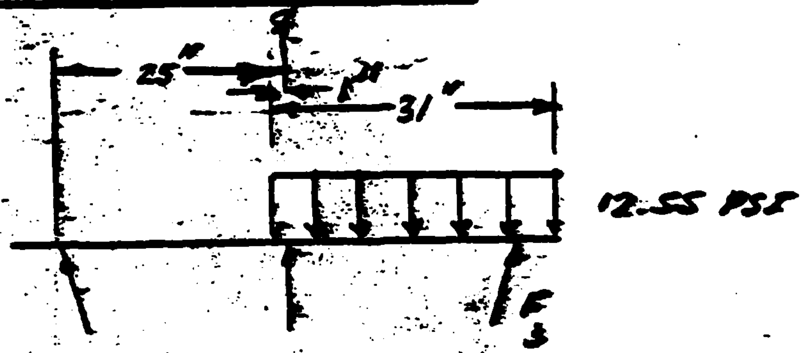
CHECK $\Sigma F = 708 \times 36 = 25,488$ LB

$$F_3 = \frac{10,215.72}{\cos 18.0446^\circ} = 10,744 \text{ LB}$$

ASSUMING 10" ARE EFFECTIVE

$F_3 =$ 1074 LB/IN.

<u>CRITICAL TRACK LOAD COND.</u>



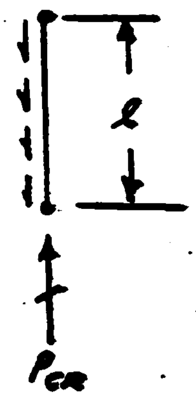
$$F_3 = \frac{31.0 \times 19.5 \times 12.55}{25.0 \times \cos 18.0446^\circ} = 237.32 \text{ LB/IN}$$

CRITICAL SHEAR FLOW COND.

$$q = \frac{82,000}{4 \times 38.3695} = 534.28 \text{ LB/IN.}$$

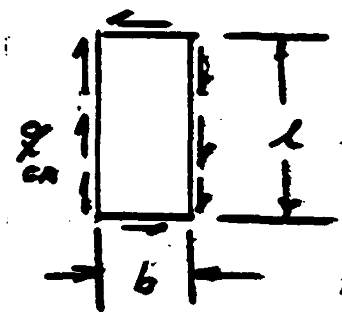
CRITICAL COLUMN AND SHEAR BUCKLING

$$P_{CR} = \frac{31.348\, E_f I}{\ell^2 + \dfrac{31.348\, E_f I}{t_c G_c}} \text{ , LB/IN}$$



$$q_{CR} = 2(\tau_{CR}\, t_f) \text{ , LB/IN}$$

$$\tau_{CR} = \frac{K \cdot \pi^2 E_f t_c t}{4 \lambda \cdot b^2}$$



$$t = 2 t_f t_c$$

$$K = 5.35 + 4.0 \left(\frac{b}{\ell}\right)^2$$

$$\lambda = 1 - \mu^2$$

$$I = \frac{t^3 - t_c^3}{12}$$

REF ~ HEXCELS BROCHURE E, "HONEYCOMB SANDWICH DESIGN", PG. 12 & TIMOSHENKO, "THEORY OF ELASTIC STABILITY", PG. 410.

THE FOREGOING EQUATIONS WERE PROGRAMMED ON AN HP-97 CALCULATOR.

INPUT DATA

b = WEB LENGTH, IN

L = WEB DEPTH, IN

μ = POISSON'S RATIO OF FACES

G_c = SHEAR MODULUS OF CORE, PSI

E_y = MODULUS OF FACES, "Y" DIR., PSI

t_c = CORE THICKNESS, IN

t_f = FACE THICKNESS, IN

OUTPUT DATA

INPUT DATA

q_{CR} CRITICAL SHEAR FLOW, LB/IN

P_{CR} CRITICAL COLUMN LOAD, LB/IN.

EXISTING AL. BRIDGE BEAM

REF ~ RICHARD HELMKE 10-19-81
(703) 664-4935

$I = 25309 \text{ IN}^4$

$C = 19.685 \text{ IN}$ (BOTTOM)

$I/C = 1284.72 \text{ IN}^3$

TOP CHORD ~ 7005-T53

$A = 29.32 \text{ IN}^2$

$I_o = 20.86 \text{ IN}^4$

$\bar{z} = 20 \text{ IN}$

BOTTOM CHORD ~

$A = 27.47 \text{ IN}^2$ (AL EQUIVALENT)

STRAIN DUE TO BENDING

$$\epsilon = \frac{2{,}163{,}000 \times 12}{1284.72 \times 10 \times 10^6} = .002002 \text{ IN/IN}$$

ϵ_{TEN} LOWER CHORD

$$\epsilon = \frac{1{,}009{,}000 \times 12}{1284.72 \times 10 \times 10^6} = .000942 \text{ IN/IN}$$

$\epsilon_{COMP.}$ LOWER CHORD

SHEAR WEB TRADE OFF STUDY

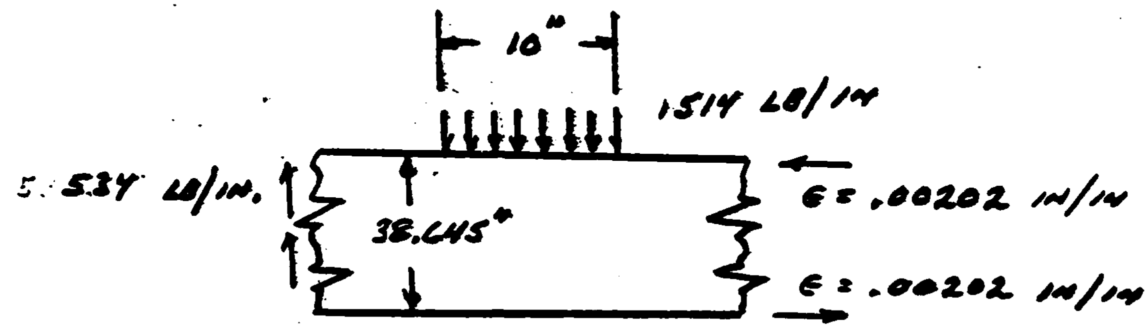
THE WEB TRADE OFF STUDY IS PERFORMED AS FOLLOWS,

1- THE RATIO OF 90° ORIENTED FIBERS TO ±45° ORIENTED FIBERS IS DETERMINED BY CALCULATING THE REQUIRED THICKNESS BASED ON COMPOSITE PROPERTIES THE LAMINATE. THE OPTIMUM RATIO IS THE POINT WHERE THE REQUIRED THICKNESS FOR STRENGTH IN THE 90° DIRECTION IS EQUAL TO THE REQUIRED THICKNESS IN THE ±45°(SHEAR) DIRECTION.

2- THE SANDWICH-WALL FACING THICKNESS IS NEXT SOLVED FOR BY AN ITERATIVE PROCESS BASED ON CALCULATING THE STRESS IN THE "X", "Y", AND "X-Y" (SHEAR) DIRECTIONS AND COMBINING THEM USING THE FAILURE CRITERION SHOWN ON PAGE 15.

3- USING THE FOREGOING MATERIAL AND FACING THICKNESSES THE CORE THICKNESS IS DETERMINED BASED ON STABILITY REQUIREMENTS USING THE COMPUTER PROGRAM (SEE PG 84) AND THE BUCKLING INTERACTION EQ (SEE PG. 15).

CRITICAL SHEAR WEB LOADS (LIMIT)



LIMIT LOADS

WEB FACING MATERIAL ~ E-GLASS / EPOXY (V_f = .50)

FS = 1.5   FATIGUE FACTOR = .31

MINIMUM THICKNESS OF FACES VS CONST.

% 90° FIBERS*	F_{xcu} PSI	t_{web} IN	F_{xtu} PSI	t IN
.90	101,502	.0722	10,469	.2469
.80	93,004	.0788	13,124	.1970
.70	84,505	.0867	15,779	.1636
.60	76,007	.0964	18,433	.1402
.50	67,509	.1085	21,088	.1226
.40	59,011	.1241	23,742	.1089 ← **
.30	50,512	.1450	26,397	.0978

* % FIBERS @ 90°, REMAINING @ ±45°

** OPTIMUM FIBER ORIENTATION RATIO (45% @ 90° & 55% @ ±45°)

TRY $t_{web} = .18$ IN

E-GLASS/EPOXY $V_f = .50$

45% @ 90° / 55% @ ±45°

$E_x = 1.522 \times 10^6$ PSI

$E_y = 3.019 \times 10^6$ PSI

$G = .9627 \times 10^6$ PSI

$\mu_{xy} = .3017$

$\mu_{yx} = .5985$

$F_{xcu} = 17{,}929$ PSI

$F_{ycu} = 63{,}260$ PSI

$F_{xyu} = 22{,}415$ PSI

FATIGUE FACTOR = .31

$\sigma_x = .00202 \times 1.522 \times 10^6$

$= 3074$ PSI

$$\sigma_y = \frac{1514}{.18} = 8411 \text{ PSI}$$

$$\tau = \frac{534}{.18} = 2967 \text{ PSI}$$

INTERACTION EQ.
(SEE PG. 15)

$$\left(\frac{3074}{.31 \times 17{,}929}\right)^2 + \left(\frac{8411}{.31 \times 63{,}260}\right)^2 - \left(\frac{3074 \times 8411}{.31^2 \times 17{,}929 \times 63{,}260}\right)$$

$$+\left(\frac{2967}{.31 \times 22{,}415}\right)^2 = .4350$$

$$FS = \frac{1}{\sqrt{.4350}} = 1.5163 \quad OK$$

TRY WR II HONEYCOMB CORE (STABILITY ANALYSIS SEE PG 34)

$b = 276$ IN

$l = 38.645$ IN

$\mu = (.3017 \times .5985)^{1/2} = .4249$

$G_c = 19{,}000$ PSI

$F_y = 3.019 \times 10^6$ PSI

FOR $F.S. = 1.5$

$$q = 1.5 \times 534 = 801 \text{ LB/IN}$$
$$p_{cr} = 1.5 \times 1514 = 2271 \text{ LB/IN}$$

} ULT. LOADS

$t_c = 1.30$

INTERACTION EQ SEE PG. 15

$$\left(\frac{2271}{2336}\right) + \left(\frac{810}{8126}\right)^2 = .9821 < 1$$

b	375.0000	***
ℓ	38.6450	***
μ	0.4245	***
G	15000.0000	***
E	3015000.000	***
t_c	1.3000	***
t_f	0.0900	***
q_{cr}	→ 8126.8149	***
p_{cr}	~~2336~~ 2685	***

UNIT WEIGHT CALCULATIONS

FACES ~ $.0675 \times .18 = .0122$ LB/IN²

CORE ~ $.0022 \times 1.30 = .0029$

ADHESIVE ~ $.043 \times .015 = .0006$

$.0157$ LB/IN²

10-19-81
SPK

CORE THICKNESS & WEIGHT STUDY

FACE ~ $\Sigma t = .12$ IN E-GLASS/EPOXY

$b = 276$ IN.

$\ell = 38.645$ IN.

$\mu = .4249$

$G_c =$

$E_y = 3.019 \times 10^6$ PSI

$t_c =$

$t_f = .09$ IN

CORE MATERIAL	G_c PSI	ρ_c LB/IN^3	t_c IN	W_c LB/IN^2	ΣW* LB/IN^2
WR II	19,000	.00220	1.300	.00286	.01566
HRH-10	7500	.00231	1.400	.00323	.01603
CR III	55,000	.00203	1.250	.00254	.01534
PVC	2200	.00359	1.900	.00682	.01962
UR.	3000	.00347	1.700	.00590	.01870

WR II	HRH-10	CR III	PVC	URETHANE FO[AM]
276.0000	276.0000	276.0000	276.0000	276.0000
38.6450	38.6450	38.6450	38.6450	38.6450
0.4249	0.4249	0.4249	0.4249	0.4249
19000.0000	7500.0000	55000.0000	2200.0000	3000.0000
3019000.000	3019000.000	3019000.000	3019000.000	3019000.000
1.3000	1.4000	1.2500	1.9000	1.7000
0.0900	0.0900	0.0900	0.0900	0.0900
8126.8149	9381.5915	7533.1572	17004.6968	13685.6103
2336.2685	2320.8871	2311.6871	2355.1323	2345.4800

NOTE: q_{cr} IS HELD APPROXIMATELY CONSTANT

* TOTAL UNIT WT. = .0128 + W_c

ACC 3/8 –.003 CORE

G_c = 40,000 PSI

	276.3000	***
	38.5450	***
	0.4249	***
	40000.0000	***
	3013900.000	***
	1.2600	***
	0.0900	***
g_{cr}	7650.0897	***
P_{cr}	[illegible]	***

W_c = .00208 × 1.26 = .00262

W_f = .0675 × .18 = .01215

W_z = .043 × .015 = .00065

.01542

10-19-81
JPR

WEB FACING MATERIAL ~ S2-GLASS/EPOXY ($V_f = .50$)

F.S. = 1.5   FATIGUE FACTOR ≈ .34

MINIMUM THICKNESS OF FACES VS CONST.

% 90° FIBERS*	F_{YCU} PSI	t_{web} IN	F_{XYU} PSI	t_{web} IN
.70	123,397	.0541	20,571	.1145
.60	110,363	.0605	24,334	.0968
.50	97,329	.0686	28,097	.0838
.40	84,295	.0792	31,859	.0739
.30	71,261	.0937	35,622	.0661

* % FIBERS AT 90°, REMAINING AT ±45°

TRY $t = .124$ IN

S2-GLASS/EPOXY $V_f = .50$
45% @ 90° / 55% @ ±45°

$E_x = 1.650 \times 10^6$ PSI
$E_y = 3.516 \times 10^6$ PSI
$G = 1.109 \times 10^6$ PSI
$\mu_{xy} = .2938$
$\mu_{yx} = .6262$
$F_{xcu} = 25,051$ PSI
$F_{ycu} = 90,812$ PSI
$F_{xyu} = 29,978$ PSI
$\rho = .24$
FATIGUE FACTOR = .34

$\sigma_x = .00202 \times 1.650 \times 10^6$

$= 3333$ PSI

$\sigma_y = \frac{1510}{.124} = 12,177$ PSI

$\tau = \frac{534}{.124} = 4306$ PSI

$$\left(\frac{3333}{25{,}051 \times .34}\right)^2 + \left(\frac{12{,}177}{90{,}812 \times .34}\right)^2 - \left(\frac{3333 \times 12{,}177}{.34^2 \times 25{,}051 \times 90{,}812}\right)$$

$$+ \left(\frac{4306}{29{,}778 \times .34}\right)^2 = .3328$$

$$FS = \frac{1}{\sqrt{.3328}} = 1.7334 \Rightarrow \text{TOO HIGH}$$

<u>TRY $t = .110$ IN.</u> S2-GLASS/EPOXY $V_f = .50$

$\sigma_x = 3333$ PSI

$$\sigma_y = \frac{1510}{.110} = 13{,}727 \text{ PSI}$$

$$\tau = \frac{534}{.110} = 4854 \text{ PSI}$$

$$\left(\frac{3333}{.34 \times 25{,}051}\right)^2 + \left(\frac{13{,}727}{.34 \times 90{,}812}\right)^2 - \left(\frac{3333 \times 13{,}727}{.34^2 \times 25{,}051 \times 90{,}812}\right)$$

$$+ \left(\frac{4854}{.34 \times 29{,}778}\right)^2 = .4036$$

$$FS = \frac{1}{\sqrt{.4036}} = 1.5741$$

10-22-84

TRY $t = .10$ IN. S2-GLASS/EPOXY $V_f = .50$

$\sigma_x = 3333$ PSI

$$\sigma_y = \frac{1510}{.10} = 15{,}100 \text{ PSI}$$

$$\tau = \frac{534}{.10} = 5340 \text{ PSI}$$

$$\left(\frac{3333}{.34 \times 25{,}051}\right)^2 + \left(\frac{15{,}100}{.34 \times 90{,}812}\right)^2 - \left(\frac{3333 \times 15{,}100}{.34^2 \times 25{,}051 \times 90{,}812}\right)$$

$$+ \left(\frac{5340}{.34 \times 29{,}978}\right)^2 = .4754$$

$$FS = \frac{1}{\sqrt{.4754}} = 1.4503$$

SUGGEST $t = .106$ IN., $FS \approx 1.5$

CORE THICKNESS & UNIT WEIGHT STUDY

$b = 276$ IN.

$\ell = 38.645$ IN.

$\mu = (.2938 \times .6262)^{1/2} = .4289$

$G_c =$

$E_f = 3.516 \times 10^6$ PSI

$t_c =$

$t_f = .053$ IN.

UC

$$t_{web} = .106 \text{ IN}$$

$$\sigma_x = 3333 \text{ PSI}$$

$$\sigma_y = \frac{1514}{.106} = 14{,}283 \text{ PSI}$$

$$\tau = \frac{534}{.106} = 5038 \text{ PSI}$$

CORE MATERIAL	G_c PSI	ρ_c LB/IN³	t_c IN	W_c LB/IN²	ΣW^* LB/IN²
ACG 3/8-.003	40,000	.00208	1.550	.00322	.01092
HRH-10	7500	.00231	1.600	.00370	.01135
URETHANE	3000	.00347	1.950	.00677	.01442
PVC	2200	.00359	2.150	.00772	.01537

$$\left.\begin{array}{l} q_{cr} = 301 \text{ LB/IN} \\ P_{cr} = 2271 \text{ LB/IN} \end{array}\right\} FS = 1.5$$

$$\left(\frac{2271}{2338}\right) + \left(\frac{301}{7695}\right)^2 = .9822 < 1 \quad OK$$

b	276.0000	275.0000	276.0000	275.0000	***
ℓ	38.6450	38.6450	38.6450	38.6450	***
μ	0.4289	0.4289	0.4289	0.4289	***
G_c	40000.0000	7500.0000	3000.0000	2200.0000	***
E_y	3516000.000	3516000.000	3516000.000	3516000.000	***
t_c	1.5500	1.6000	1.9500	2.1500	***
t_f	0.0530	0.0530	0.0530	0.0530	***
q_{cr} →	7695.9156	9017.6484	12097.9183	14670.6057	***
P_{cr} →	2338.9245	2322.9217	2311.1042	2340.4020	***

$$W_f = 2 \times .053 \times .0665 = .00705$$

$$W_2 = .043 \times .015 = \underline{.0006}$$

$$.00765 \text{ LB/IN}^2$$

CORE THICKNESS VS FACING THICKNESS STUDY. FACING ~ S2-GLASS / EPOXY

CORE ~ ACG 3/8 - .003

$b = 276$ IN.

$\ell = 38.645$ IN.

$\mu = .4289$

$G_c = 40{,}000$ PSI $\qquad \rho_c = .00208$ LB/IN^3

$E_y = 3.516 \times 10^6$ PSI $\qquad \rho_f = .0665$ LB/IN^3

$t_c = 1.550,\ 1.410\ \ 1.310$ IN.

$t_f = .0530,\ .0630,\ .0730$ IN.

$\Sigma W = .01892 \quad .01196 \quad .01308$ LB/IN.

$W_z = .043 \times .015 = .00065$

$W_f = 2\, t_f\, (.0665) =$

$W_c = t_c\,(.00208) =$ ________

Σ

	276.000 ***	276.000 ***	276.000 *
	38.645 ***	38.645 ***	38.645 ***
	0.429 ***	0.429 ***	0.429 ***
	40000.000 ***	40000.000 ***	40000.000 ***
	3516000.000 ***	3516000.000 ***	3516000.000 ***
	1.550 ***	1.410 ***	1.310 ***
	0.053 ***	0.063 ***	0.073 ***
P_{CR}	7695.916 ***	7646.833 ***	7729.218 ***
P_{CR}	2338.924 ***	2316.523 ***	2333.819 ***

10-23-81

WEB FACING MATERIAL ~ T-300/EPOXY V_f = .50

FS = 1.5 , FATIGUE FACTOR = .615

MINIMUM THICKNESS OF FACING VS. CONST.

% 90° FIBERS *	F_{ycu} PSI	t_{web} IN	F_{xyu} PSI	t_{web} IN
.70	119,525	.0309	24,810	.0525
.60	109,367	.0338	28,005	.0465
.50	99,208	.0372	31,200	.0417 ←
.40	89,050	.0415	34,394	.0379
.30	78,891	.0468	37,589	.0346

* % FIBERS AT 90°, REMAINING AT ±45°

TRY t_{web} = .054

σ_x = .00202 × 2.650 × 10^6

= 5353 PSI (LIMIT)

$\sigma_y = \frac{1514}{.054} = 28{,}037$ PSI

$\tau = \frac{534}{.054} = 9889$ PSI

T-300/EPOXY V_f = .50

45% @ 90°/55% @ ±45°

E_x = 2.650 × 10^6 PSI

E_y = 8.471 × 10^6 PSI

G = 2.561 × 10^6 PSI

μ_{xy} = .2376

μ_{yx} = .7596

F_{xcu} = 29,266 PSI

F_{ycu} = 94,129 PSI

F_{xyu} = 32,787 PSI

ρ = .053

FATIGUE FACTOR = .615

$$\left(\frac{5353}{.615 \times 29{,}266}\right)^2 + \left(\frac{28{,}037}{.615 \times 94{,}129}\right)^2 - \left(\frac{5353 \times 28{,}037}{.615^2 \times 29{,}266 \times 94{,}129}\right)$$

$$+ \left(\frac{2889}{.615 \times 32{,}797}\right)^2 = .4194$$

$$FS = \frac{1}{\sqrt{.4194}} = 1.5442 \quad \text{OK}$$

CORE THICKNESS & UNIT WEIGHT STUDY

$b = 276$ IN

$\ell = 38.645$ IN

$\mu = (.2376 \times .7592)^{1/2} = .4248$

$G_c =$

$E_y = 8.471 \times 10^6$ PSI

$t_c =$

$t_f = .027$ IN.

CORE MATERIAL	G_c PSI	ρ_c LB/IN^3	t_c IN	W_c LB/IN^2	ΣW LB/IN^2
ACG-3/8-.003	40,000	.00208	1.410	.00293	.00644
HRH-10	7500	.00231	1.550	.00358	.00709
URETHANE	3000	.00347	1.840	.00638	.00989
PVC	2200	.00359	2.000	.00718	.01069

$W_f = 2 \times .027 \times .0530 = .00286$

$W_Z = .043 \times .015 = .00065$

$\Sigma\ .00351$

276.0000	276.0000	276.0000	276.0000	***
38.6450	38.6450	38.6450	38.6450	***
0.4248	0.4248	0.4248	0.4248	***
2200.0000	7500.0000	3000.0000	40000.0000	***
8471000.000	8471000.000	8471000.000	8471000.000	***
2.0000	1.5500	1.8400	1.4100	***
0.0270	0.0270	0.0270	0.2270	***
15345.5491	9252.6046	13003.8560	7670.0753	***
2310.6394	2342.7611	2390.2816	[illegible]	***

11-6-81

WEB FACING MATERIAL ~ T-300 / EPOXY $V_f = .50$

- ANALYSIS BASED ON MINIMUM THICK. THAT CAN BE WOUND.

$t_{ply} = .0085$ IN.

45% @ 90° / 55% @ ± 45°

$t_f = 2 \times .0085\,(1 + .45/.55) = .0309$ IN.

$t_{web} = 2 \times .0309 = .0618$ IN.

$\sigma_x = .00202 \times 2.650 \times 10^6 = 5353$ PSI

$$\sigma_y = \frac{1514}{.0618} = 24{,}498 \text{ PSI}$$

$$\tau = \frac{534}{.0618} = 8641 \text{ PSI}$$

$$\left(\frac{5353}{.615 \times 29{,}266}\right)^2 + \left(\frac{24{,}498}{.615 \times 94{,}129}\right)^2 - \left(\frac{5353 \times 24{,}498}{.615^2 \times 29{,}266 \times 94{,}129}\right)$$

$$\left(\frac{8641}{.615 \times 32{,}797}\right)^2 = .3252$$

$$FS = \frac{1}{\sqrt{.3252}} = 1.7535$$

11-6-81

CORE THICKNESS & UNIT WEIGHT STUDY

$b = 276$ IN

$\ell = 38.645$ IN.

$\mu = .4248$

$G_c =$

$E_f = 8.471 \times 10^6$ PSI

$t_c =$

$t_f = .0309$ IN.

CORE MATL.	G_c PSI	ρ_c LB/IN^3	t_c IN	W_c LB/IN^2	ΣW LB/IN^2
ACG-3/8-.003	40,000	.00208	1.320	.00275	.00667
HRH-10	7,500	.00231	1.450	.00335	.00727
URETHANE	3000	.00347	1.730	.00600	.00992
PVC	2200	.00359	1.920	.00689	.01081

$W_f = 2 \times .0309 \times .0580 = .00358$

$W_a = .043 \times .015 = \underline{.00065}$

$\Sigma\ .00392$ LB/IN^2

275.0000	276.0000	276.0000	276.0000 ***
38.6450	38.6450	38.6450	38.6450 **
0.4248	0.4248	0.4248	0.4248 ***
40000.0000	7500.0000	3000.0000	2200.0000 ***
8471000.000	8471000.000	8471000.000	8471000.000 ***
1.3200	1.4500	1.7300	1.9200
0.0309	0.0309	0.0309	0.0309
7725.0599	9302.4739	13197.3131	16227.1019
2341.1766	2320.4928	2316.7779	2319.7221

WEB FACING MATERIAL ~ S2-GLASS & T-300 /EPOXY

$FS = 1.5$

$F.F. = .615$

$V_f = .50$

90° FIBERS ~ T-300

±45° FIBERS ~ S2-GLASS

% 90° FIBERS*	F_{ycu} PSI	t_{web} IN	F_{xyu} PSI	t_{web} IN.
70	108,441	.0341	16,126	.0808
60	94,588	.0390	16,426	.0793
50	80,734	.0457	16,726	.0779 ←
40	66,881	.0552	17,027	.0765
30	53,028	.0696	17,326	.0752

* % FIBERS AT 90°, REMAINING AT ±45°

TRY $t_{web} = .104$ IN

$\sigma_x = .00202 \times 1.663 \times 10^6$

$= 3359$ PSI

$\sigma_y = \dfrac{1514}{.104} = 14,557$ PSI

$\tau = \dfrac{534}{.104} = 5135$ PSI

45% AT 90° T-300

55% AT ±45° S2-GLASS

$E_x = 1.663 \times 10^6$ PSI

$E_y = 8.122 \times 10^6$ PSI

$G = 1.177 \times 10^6$ PSI

$\mu_{xy} = .1362$

$\mu_{yx} = .6651$

$F_{xcu} = 9469$ PSI

$F_{ycu} = 73,808$ PSI

$F_{xyu} = 16,876$ PSI

$\rho = .0604$ LB/IN^3

FATIGUE FACTOR = .615

$$\left(\frac{3359}{.615 \times 9469}\right)^2 + \left(\frac{14,557}{.615 \times 73,808}\right)^2 - \left(\frac{3359 \times 14,557}{.615^2 \times 9469 \times 73,808}\right)$$

$$+\left(\frac{5135}{.615 \times 16,876}\right)^2 = .4954$$

$$FS = \frac{1}{\sqrt{.4954}} = 1.4208$$

TRY $t_{web} = .110$ IN.

$\sigma_x = 3359$ PSI

$$\sigma_y = \frac{1514}{.110} = 13,764 \text{ PSI}$$

$$\tau = \frac{534}{.110} = 4855 \text{ PSI}$$

$$\left(\frac{3359}{.615 \times 9469}\right)^2 + \left(\frac{13,764}{.615 \times 73,808}\right)^2 - \left(\frac{3359 \times 13,764}{.615^2 \times 9469 \times 73,808}\right)$$

$$+\left(\frac{4855}{.615 \times 16,876}\right)^2 = .4686$$

$$FS = \frac{1}{\sqrt{.4686}} = 1.4609$$

$t_{web} = .114$ IN. $\qquad$ $FS \approx 1.5$

$\sigma_x = 3359$

$\sigma_y = \dfrac{1514}{.114} = 13,280$ PSI

$\tau = \dfrac{534}{.114} = 4684$ PSI

10-27-81

CORE THICKNESS & UNIT WEIGHT STUDY

$b = 276$ IN

$l = 38.645$ IN

$\mu = (.1362 \times .6651)^{1/2} = .3010$

$G_c =$

$E_y = 8.122 \times 10^6$ PSI

$t_c =$

$t_f = .057$

CORE MATERIAL	G_c PSI	ρ_c LB/IN³	t_c IN	W_c LB/IN³	ΣW LB/IN³
ACG-3/8-.003	40,000	.00208	.980	.00204	.00958
HRH-10	7500	.00231	1.120	.00259	.01013
URETHANE	3000	.00347	1.430	.00496	.01250
PVC	2200	.00359	1.630	.00585	.01339

$W_f = 2 \times .057 \times .0604 = .00689$

$W_I = .043 \times .015 = \underline{.00065}$

$.00754$ LB/IN²

	276.0000	276.0000	267.0000	276.0000
	38.6450	38.6450	38.6450	38.6450
	0.3010	0.3010	0.3010	0.3010
	40000.0000	7500.0000	3000.0000	2200.0000
	8122000.000	8122000.000	8122000.000	8122000.000
	0.9800	1.1200	1.4300	1.6300
	0.0570	0.0570	0.0570	0.0570
P_{cr}	7617.3405	9102.5217	14700.7165	18987.6144
P_{cR}	2324.9570	2319.9556	2344.2378	2333.7522

WEB FACING MATERIAL ~ S2-GLASS & HMS / EPOXY

TRY $t_{web} = .190$ IN.

$\sigma_x = .00202 \times 1.598 \times 10^6$
$= 3228$ PSI

$\sigma_y = \dfrac{1514}{.190} = 7968$ PSI

$\tau = \dfrac{534}{.190} = 2811$ PSI

$V_f = .50$
90° FIBERS ~ HMS
±45° FIBERS ~ S2-GLASS
45% @ 90°
55% @ ±45°
$E_x = 1.598 \times 10^6$ PSI
$E_y = 11.88 \times 10^6$ PSI
$G = 1.177 \times 10^6$ PSI
$\mu_{xy} = .0933$
$\mu_{yx} = .6935$
$F_{xcu} = 5338$ PSI
$F_{ycu} = 59{,}753$ PSI
$F_{xyu} = 9832$ PSI
$\rho = .0611$
FATIGUE FACTOR = .615

.9668

$$\left(\frac{3228}{.615 \times 5338}\right)^2 - \underline{\qquad\qquad} - \underline{\qquad\qquad\qquad}$$

$$\underline{\qquad\qquad} =$$

DESIGN IS NOT PRACTICAL DUE TO THE LOW F_{xcu}

WEB FACING MATERIAL ~ HMS / EPOXY

TRY t_{web} = .064 IN.

$V_f = .58$
45% @ 90°
55% @ ±45°
$E_x = 3.395 \times 10^6$ PSI
$E_y = 12.26 \times 10^6$ PSI
$G = 3.696 \times 10^6$ PSI
$\mu_{xy} = .2317$
$\mu_{yx} = .8365$
$F_{xcu} = 20,904$ PSI
$F_{ycu} = 72,824$ PSI
$F_{xyu} = 25,885$ PSI
$\rho = .0545$ LB/IN³
FATIGUE FACTOR = .615

$$\sigma_x = .00202 \times 3.395 \times 10^6 = 6858 \text{ PSI}$$

$$\sigma_y = \frac{1514}{.064} = 23,656 \text{ PSI}$$

$$\tau = \frac{534}{.064} = 8344 \text{ PSI}$$

$$\left(\frac{6858}{.615 \times 20,904}\right)^2 + \left(\frac{23,636}{.615 \times 72,824}\right)^2 - \left(\frac{6858 \times 23,636}{.616^2 \times 20,904 \times 72,824}\right)$$

$$+\left(\frac{8344}{.615 \times 25,885}\right)^2 = .5563$$

$$FS = \frac{1}{\sqrt{.5563}} = 1.3408$$

TRY t_{web} = .074 IN.

σ_x = 6858 PSI

$$\sigma_y = \frac{1514}{.074} = 20,459 \text{ PSI}$$

$$\tau = \frac{534}{.074} = 7216 \text{ PSI}$$

$$\left(\frac{6858}{.615 \times 20,904}\right)^2 + \left(\frac{20,459}{.615 \times 72,824}\right)^2 - \left(\frac{6858 \times 20,459}{.615^2 \times 20,904 \times 72,824}\right)$$

$$+\left(\frac{7216}{.615 \times 25,885}\right)^2 = .4550$$

$$FS = \frac{1}{\sqrt{.4550}} = 1.4824$$

$t_{web} = .076$ IN $\quad FS \approx 1.5$

CORE THICKNESS & UNIT WEIGHT STUDY

$b = 276$ IN

$\ell = 38.645$ IN

$\mu = (.2317 \times .8365)^{1/2} = .4402$

$G_c =$

$E_y = 12.26 \times 10^6$ PSI

$t_c =$

$t_f = .028$ IN.

$\sigma_x = 6850$ PSI

$\sigma_y = \frac{1514}{.076} = 19{,}921$ PSI

$\tau = \frac{534}{.076} = 7026$ PSI

CORE MATERIAL	G_c PSI	ρ_c LB/IN^3	t_c IN	W_c LB/IN^2	ΣW LB/IN^3
ACG-3/8-.003	40,000	.00208	.990	.00206	.00685
HRH-10	7500	.00231	1.130	.00261	.00740
URETHANE	3000	.00347	1.420	.00493	.00972
PVC	2200	.00359	1.620	.00582	.01061

$$W_f = 2 \times .038 \times .0545 = .00414$$

$$W_2 = .043 \times .015 = \underline{.00065}$$

$$\Sigma \quad .00479 \ LB/IN^2$$

	276.00000	276.0000	276.0000	276.0000
	38.64500	38.6450	38.6450	38.6450
	0.44020	0.4402	0.4402	0.4402
	40000.00000	7500.0000	3000.0000	2200.0000
	12260000.00	12260000.00	12260000.00	12260000.00
	0.99000	1.1300	1.4200	1.6200
	0.03600	0.0380	0.0380	0.0380
q_{cr}	7976.64261	10344.0453	15227.3866	21052.4311
ρ_{cr}	2342.64269	2337.5667	2313.4012	2310.3041

10-27-81
9PR

WEB MODULE DESIGN SUMMARY

PARAMETER	WEB FACE MATERIAL				
	E-GLASS	S2-GLASS	T-300	HMS	S2/T-300
t_f, IN.	.090	.053	.027	.038	.057
σ_x, PSI	3074	3333	5353	6850	3359
σ_y, PSI	8411	14,283	28,037	19,921	13,280
τ, PSI	2967	5038	9889	7026	4684
AGC 3/8-.003					
t_c, IN	1.260	1.550	1.410	.980	.980
W_c, LB/IN^2	.00262	.00322	.00293	.00206	.00204
ΣW, LB/IN^2	.01542	.01092	.00644	.00685	.00958
HRH-10					
t_c, IN	1.400	1.600	1.550	1.130	1.120
W_c, LB/IN^2	.00323	.00370	.00358	.00261	.00259
ΣW, LB/IN^2	.01603	.01135	.00709	.00740	.01013
URETHANE					
t_c, IN	1.700	1.950	1.840	1.420	1.430
W_c, LB/IN^2	.00590	.00677	.00638	.00493	.00496
ΣW, LB/IN^2	.01870	.01442	.00989	.00972	.01250
PVC					
t_c, IN	1.900	2.150	2.000	1.620	1.630
W_c, LB/IN^2	.00682	.00772	.00718	.00582	.00585
ΣW, LB/IN^2	.01962	.01537	.01069	.01061	.01339

WEB MODULE DESIGN SUMMARY

(INCLUDING INSULATION & MIN. THICKNESSES)

PARAMETER	E-GLASS	S2-GLASS	T-300	HMS	S2 & T-300
	WEB FACE MATERIAL				
t_f, IN	.090	.053	.0309	.038	.057
t_i^*, IN	.0	.0	.004	.004	.004
σ_x, PSI	3074	3333	5353	6850	3359
σ_y, PSI	8411	14,283	24,497	19,921	13,280
τ, PSI	2967	5038	8641	7026	4634
ACG-3/8-.003					
t_c, IN	1.260	1.550*	1.320*	.990	.980
ΣW, LB/IN^2	.01542	.01092	.00719	.00736	.01009
HRH-10					
t_c, IN	1.400	1.600	1.450	1.136	1.120
ΣW, LB/IN^2	.01608	.01135	.00778	.00791	.01064
URETHANE					
t_c, IN	1.700	1.950	1.730	1.420	1.430
ΣW, LB/IN^2	.01870	.01442	.01043	.01023	.01301
PVC					
t_c, IN	1.900	2.150	1.920	1.620	1.630
ΣW, LB/IN^2	.01962	.01537	.01132	.01112	.01890

* INSULATION THICKNESS PER FACE

BOTTOM CHORD/WEB JOINT STUDY

CRITICAL DISTRIBUTED LOAD (BOTTOM CHORD) COND.

$$F = \frac{82{,}000}{40 \times 4 \times \cos 12.0446^\circ} = 539 \text{ LB/IN/WEB.}$$

CRITICAL ROLLER LOAD (BOTTOM CHORD) COND.

F = 36,170 LB

WIDTH OF ROLLER = 6.0 IN

DIAMETER OF ROLLER = 16.0 IN.

REF ~ S. TIMOSHENKO, "THEORY OF ELASTICITY," PAGE 282

HALF CONTACT WIDTH $b = 1.52 \sqrt{\frac{P'R}{E}}$

MAX. CONTACT PRESSURE $q_0 = 0.418 \sqrt{\frac{P'E}{R}}$

$P' = 36{,}170$ LB/IN (ASSUMING 1" WIDTH)

$$b = 1.52 \sqrt{\frac{36{,}170 \times 8.0}{10 \times 10^6}} = .2586 \text{ IN}$$

$$q_0 = 0.418 \sqrt{\frac{36{,}170 \times 10 \times 10^6}{8.0}} = 88{,}880 \text{ LB/IN.}$$

∴ THE WEB MODULE IS SIZED FOR A UNIT LOADING OF 1514 LB/IN

REDUCTION FACTOR DUE TO DEPTH

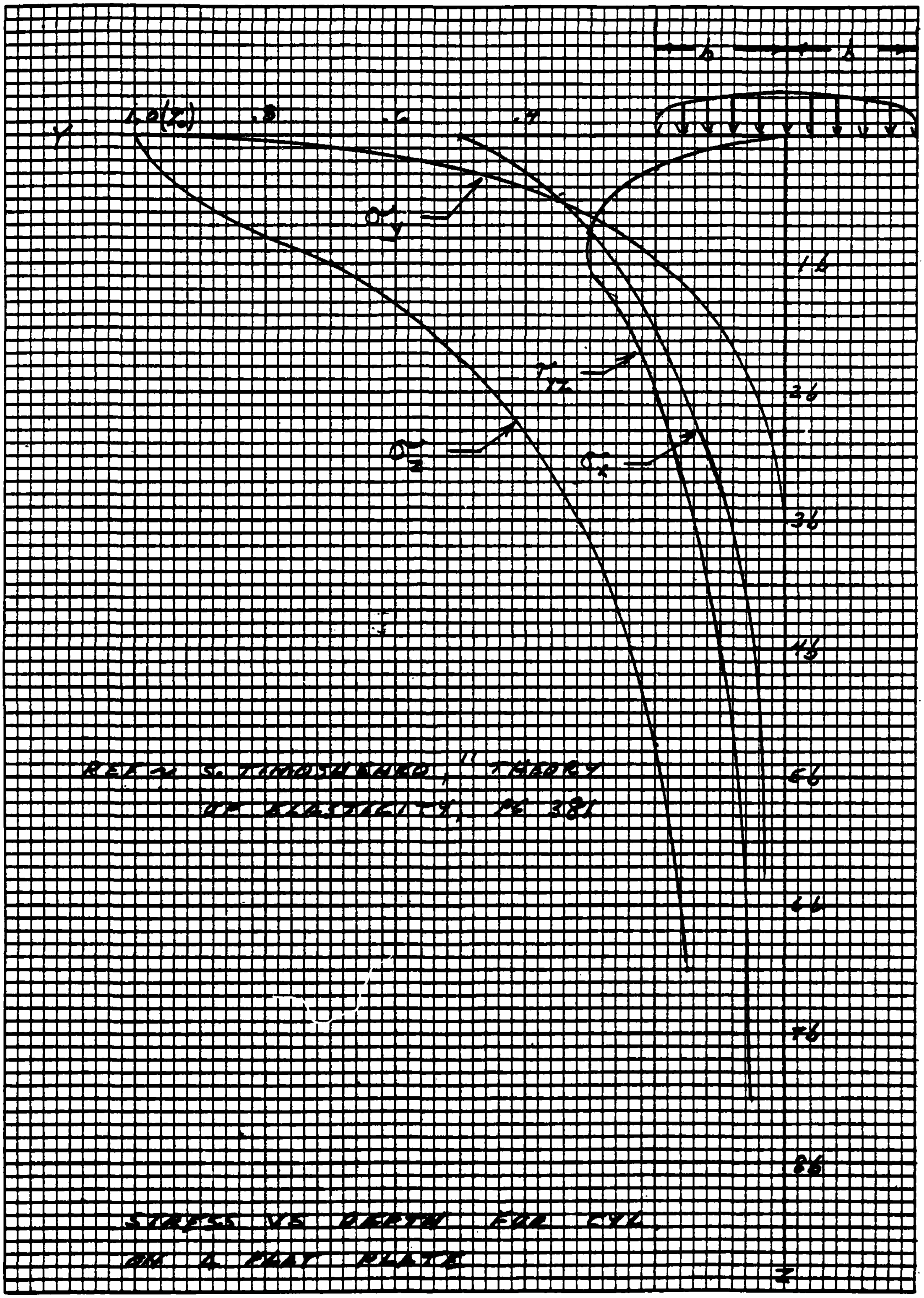
$$K = \frac{1514}{88{,}880} = .0170$$

DEPTH $\approx 10\,b$ (SEE FIG. FOR STRESS VS DEPTH FOR CYL ON A FLAT PLATE)

DEPTH = 10 × .2586 = 2.586 IN.*

* DEPTH TO BASIC WEB THICKNESS FROM SURFACE OF LOWER CHORD.

10-27-81



1.0(Z)
.8
.6
.4
b
b
σy
τyz
σz
σx
1b
2b
3b
4b
6b
6b
7b
8b
z
REF - S. TIMOSHENKO, "THEORY OF ELASTICITY", PG 381
STRESS VS DEPTH FOR CYL ON A FLAT PLATE

CT

THE AL. WEB THICKNESS VS. DEPTH FOR $b = .2586$ IN & $q_o = 88,880$ LB/IN ARE,

DEPTH IN.	σ_z LB/IN	τ LB/IN	t_z^* IN	t_τ^* IN	t_z^{**} IN	t_τ^{**} IN
0	88,880	0	1.990	0		
.26	62,216	26,664	1.393	1.053		
.52	39,996	17,776	.895	.702		
.78	28,441	12,443			.853	.667
1.03	21,331	8,888			.640	.476
1.29	16,887	6,222			.507	.333
1.55	14,220	5,332			.427	.286

* 7075 - T73 AL

$$F_c = \frac{67,000}{1.5} = 44,667 \text{ PSI}$$

$$F_s = \frac{38,000}{1.5} = 25,333 \text{ PSI}$$

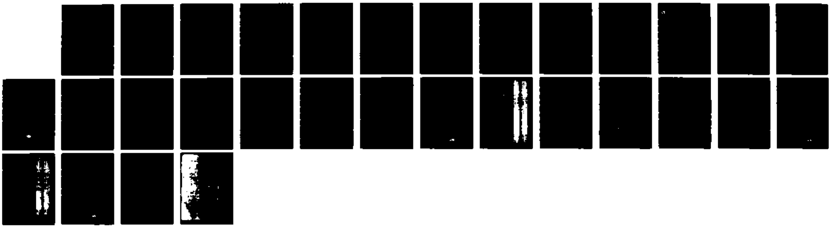
** 7005 - T53 AL.

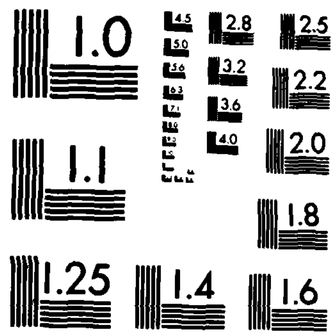
$$F_c = \frac{50,000}{1.5} = 33,333 \text{ PSI}$$

$$F_s = \frac{28,000}{1.5} = 18,666 \text{ PSI}$$

AD-A128 010 BRIDGE WOUND WEB MODULE(U) EDO CORP SALT LAKE CITY UT FIBER SCIENCE DIV 1983

UNCLASSIFIED F/G 13/13 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

THE MINIMUM FRICTION COEFFICIENT ASSUMING THE SHEAR IS CARRIED BY FRICTION IS,

$$f = \frac{\tau}{\sigma_z}$$

DEPTH IN	f
0	0
.26	.429
.52	.444
.78	.438

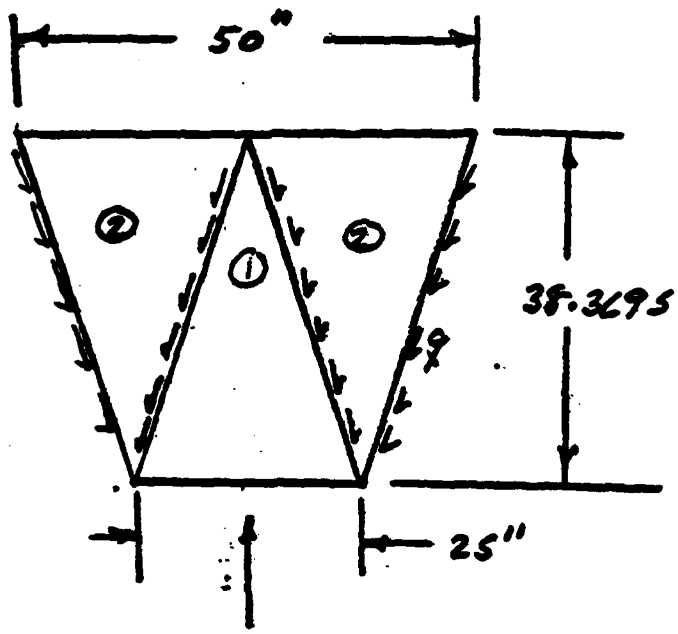
THESE VALUES ARE TOO HIGH, SUGGEST SERRATED SURFACES OR ONE PIECE CONSTRUCTION

12-1-81
9PK

BULKHEAD ANALYSIS

$V = 82{,}000$ LB

$FS = 1.5$



$$q_{SV} = \frac{123{,}000}{4 \times 38.37} = 801.4 \text{ LB/IN}$$ (INCLUDES FS = 1.5)

± 45° S2-GLASS/EPOXY

FATIGUE FACTOR = .34

$F_{SU} = .34 \times 46{,}910 = 15{,}949$ PSI

$$t_1 = \frac{2 \times 801.4}{15{,}949} = .1005 \text{ IN}$$

$$t_2 = \frac{801.4}{15{,}941} = .0503 \text{ IN.}$$

SANDWICH WALL PANEL UNDER EDGEWISE SHEAR LOAD
EQUAL ISOTROPIC FACES

REF ~ MIL-HDBK-23A, CHAPTER 6

ENTER

t FACE THICKNESS, IN

t_c CORE THICKNESS, IN

a PANEL WIDTH, IN

b PANEL LENGTH, IN

E FACE MODULUS, PSI

μ FACE POISSON'S RATIO

G CORE SHEAR MODULUS

CALCULATE

$$h = t + t_c$$

$$D = \frac{E t h^2}{2(1-\mu^2)}$$

$$\frac{b}{a}$$

$$V = \frac{\pi^2 D}{b^2 h G}$$

OUTPUT

b/a

V

ENTER

K_M & K_{MO} (SEE REF FIG 6-7 — 6-11)

CALCULATE

$$K_F = K_{MO}\left(\frac{t^2}{3h}\right)$$

$$K = K_F + K_M$$

$$F_S = \frac{\pi^2 K}{4}\left(\frac{h}{b}\right)^2 \frac{E}{(1-\mu^2)}$$

OUTPUT

b/Z, V, t, t_c, Z, b, E, μ, G, K_M, K_{MO}, F_{SCR}

STORAGE

$P \rightarrow$	0	1	2	3	4	5	6	7	8	9
	b	Z	t_c	t	G	μ	E	h	D	V

$S \rightarrow$	0	1	2	3	4
	K_{MO}	K_M	K_F	K	F_S

TRY SANDWICH WALL CONSTRUCTION

$t_f = .05$ IN.

$t_c = .50$ IN

$a = 38.37$ IN

$b = 25.00$ IN

$E = .8372 \times 10^6$ PSI } S2-GLASS/EPOXY $V_f = .50$

$\mu = .8111$ } $\alpha = \pm 45°$

$G = 40{,}000$ PSI   ACG-1/8-.003 HONEYCOMB

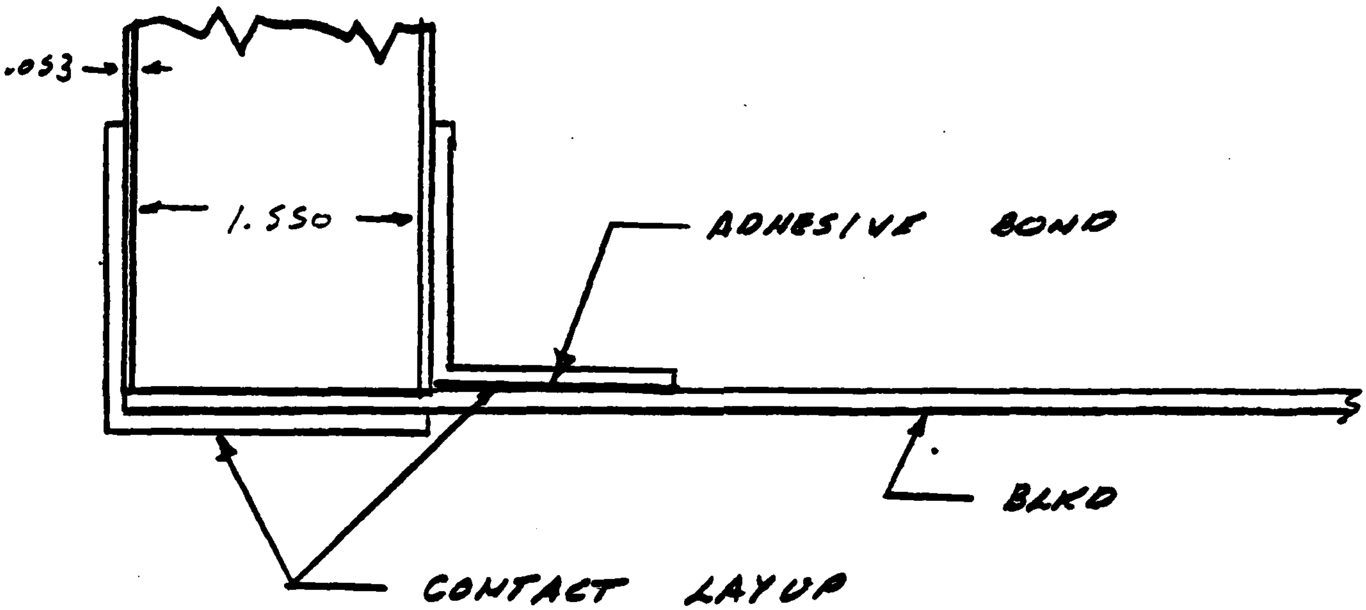
$b/a = .6516$ } $K_M = 6.25$ } REF ~ MIL-HDBK-23A

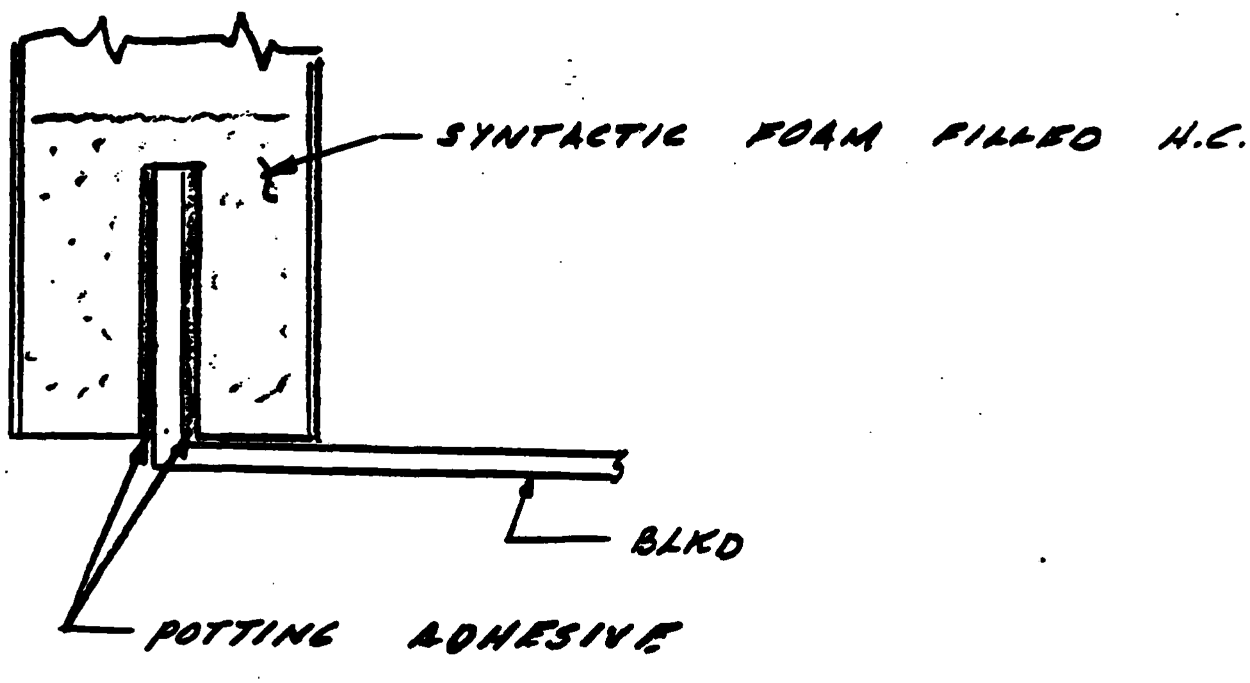
$V = .0284$ } $K_{MO} = 6.95$ } FIG 6-7

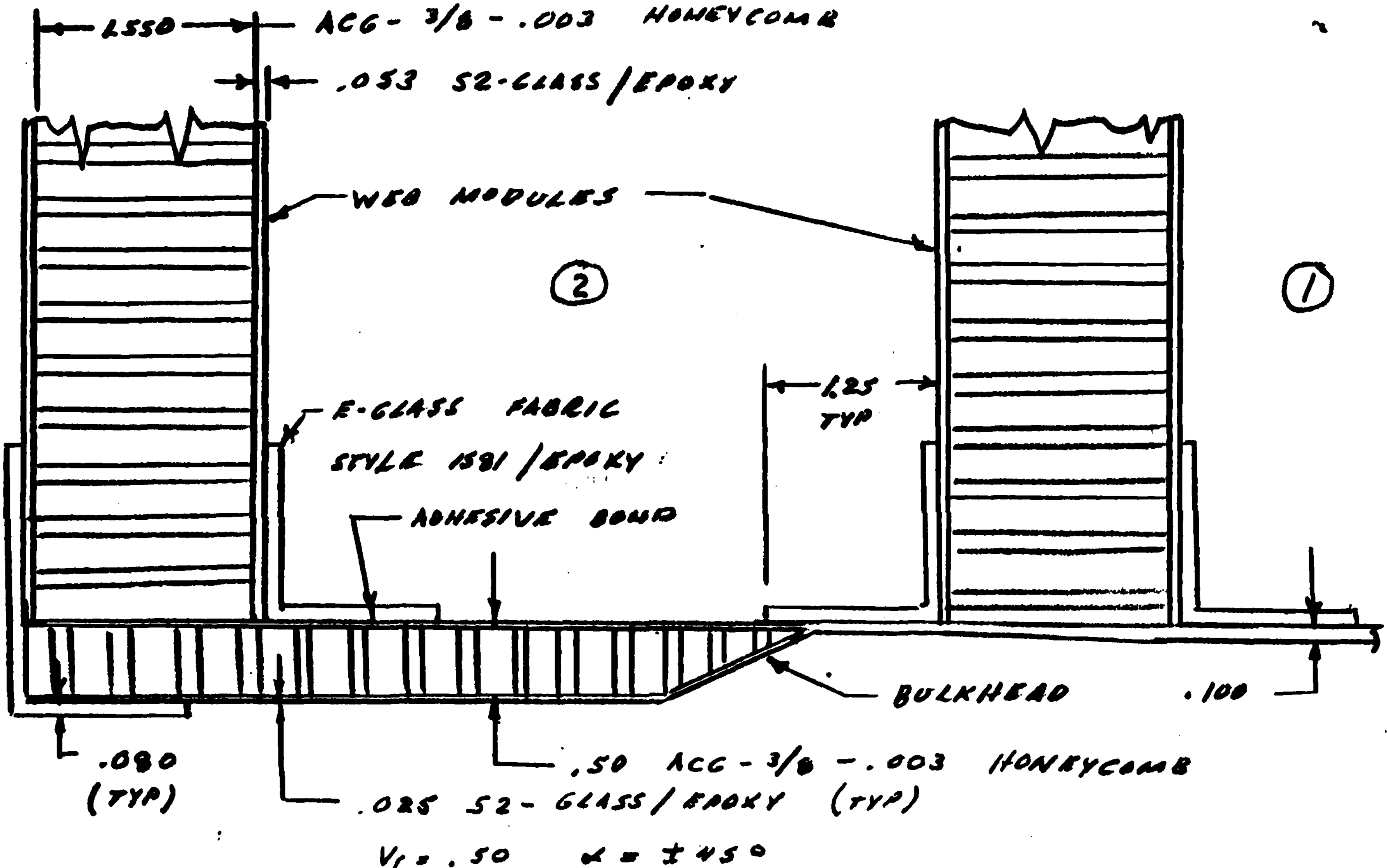
b/a	0.6516	0.6516	0.6516	0.6516	0.6516
V	0.0284	0.0300	0.0300	0.0298	0.0329
t_f	0.0500	0.0500	0.0500	0.0250	0.0250
t_c	0.5000	0.4700	0.4500	0.5000	0.4500
a	38.3700	38.3700	38.3700	38.3700	38.3700
b	25.0000	25.0000	25.0000	25.0000	25.0000
E	837200.0000	837200.0000	837200.0000	837200.0000	837200.0000
μ	0.8111	0.8111	0.8111	0.8111	0.8111
G	40000.0000	40000.0000	40000.0000	40000.0000	40000.0000
K_M	6.2500	6.2500	6.2500	6.7000	6.2500
K_{MO}	6.9500	6.9500	6.9500	6.9500	6.9500
F_{cr}	18320.5644	16382.7599	15760.8437	17854.5273	13637.2719

12-1-81

WEB MODULE BULKHEAD ATTACHMENTS







WEB MODULE / BULKHEAD JOINT

12-2-81
9 Pke

G MATERIAL COSTS

1. HONEYCOMB

	Type	Mfg By	THICKNESS, IN 1.25	1.625	2.000
Alum.	ACG 3/8-.003	Hexcel	$ 2.30/FT^2	$ 2.89/FT^2	$ 3.49/FT^2
Alum.	CRIII 2024-.0015	Hexcel	17.16	22.30	27.45
Alum.	CRIII 5052-.0015	Hexcel	5.33	6.93	8.53
Nomex	HRH 1/4-4.0(5)	Hexcel	13.21	17.17	21.13
Nomex	HRH 1/4-4.0(5)	Ciba-Geigy	7.25	9.29	11.33
6.2 LB/FT^3	PVC Foam	Klegecell	7.00	9.31	11.00
6 LB/FT^3	Polyurethane Foam	Gen.Plastics	1.69	2.12	2.59

2. FIBER

TYPE	MFG BY	COST, $/LB
E Glass	Owens-Corning	0.95
S2 Glass	Owens-Corning	3.87
T300 Graphite	Union Carbide	32.00
HMS Graphite	Hercules	50.00

3. RESIN

TYPE	MFG BY	COST, $/LB
EA 826/TONOX LC	Shell Chem/US Rubber	$1.724/LB

ADDENDUM II

DEPARTMENT OF THE ARMY B. Ballinger/111/703-664-5140
US ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-PEA

5 JAN 1982

SUBJECT: DAAK70-81-C-0210, Wound Web Bridge Modules

Fiber Science, Inc.
ATTN: Mr. H. D. Goff
506 Billy Mitchell Road
Salt Lake City, Utah 84116

Gentlemen:

Reference FSI Letter No. 112236, dated 10 December 1981, with Phase I Report relative to subject contract.

Phase I Report has been reviewed and comments/direction follow:

a. Recommendation 1 - Materials. The recommendation to use Hexcel ACG 3/8-.003 aluminum honeycomb core material is Accepted. The recommendation to use S2 Fiberglass Epoxy Composite Material is open to considerable question.

Government Position - The graphite epoxy skin material shown in the minimum weight position is much more weight efficient than the recommended compromise position of FSI (246# vs 425#). The higher cost ($3006 vs $1665) is due to FSI's selection of T300 graphite fiber and the Government requests that FSI investigate the use of Great Lakes Carbon Fiber Fortafil 3T or 4T as a possible alternative. These materials bracket the T300 material in properties and sell for $18 per lb. This material is available in a 40,000 tow size only, but a sincere effort to apply this material (or a cheap similar material) in the light of its much lower price should be made. A realistic module price of $2000 and weight of 250 pounds should be possible.

b. Recommendation 2 - Process. The lay-up option D which was recommended and acceptable for S2 glass is not shown to be cost effective for graphite fiber. The 18.02 figure shown with the asterisk is open to considerable question.

Government Position - FSI should determine the actual cost of the Knytex triaxial non-woven fabric for the low cost graphite fiber selected. A trial run may be necesary. This should not be costly since the material produced would be used for one module. If the Knytex process is not cheaper than alternative B, then alternative B of the "W" process will be used. Since both processess are hand lay-ups, the tooling will be the same with only fabric production differences.

DRDME-PEA

SUBJECT: DAAK70-81-C-0210, Wound Web Bridge Modules

c. Recommendation 3 - Drawings. Class C drawings are Rejected. Class B is recommended.

Government Position - Follow contract requirements for drawings.

d. Recommendation 4 - Tooling Drawings are Accepted.

e. Recommendation 5 - Level of fabrication is Accepted.

f. Recommendation 6 - Tooling fabrication is Accepted.

g. Recommendation 7 - Panels need not be interchangeable is Accepted.

h. The joint details shown in Figures II through V are Accepted in concept for further dimensioning. Final acceptance will be withheld until full detail is made available.

Should you have any questions relative to the above, contact Mrs. B. Ballinger, (703) 664-5140.

Sincerely,

HERB ROTHSCHILD
Contracting Officer

ADDENDUM III

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

DRAWN	
CHECK	
STRESS	
WEIGHT	
Q.C.	
MFG ENGR	
PROJ ENGR S. Twitchell	8-10-82
PROJ MGR	
APPROVAL J.V. Oaines	8-13-82
APPROVAL C.C. Petrunk Jr.	8/13/82
RELEASE DATE	

FIBER SCIENCE, INC.
SALT LAKE CITY, UTAH 84116

TITLE
BRIDGE WOUND WEB MODULE
PHASE II REPORT - SA 3032-J-0002

SIZE	CODE IDENT	DWG NO	REV
A	32500		

SCALE:	UNIT WT:	SHEET	OF

"The views, opinions, and/or findings contained in the report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation."

I. INTRODUCTION

The Wound Bridge Web contract is an effort to reduce the weight of the existing bridge. The wound bridge web contract, which provides for the determination of contract feasibility, design, fabrication, test and assembly of two bridge web modules, was received at Fiber Science on September 28, 1981.

Phase II of the contract, entitled "ENGINEERING DESIGN AND DOCUMENTATION", includes (1) manufacture and test of samples to verify properties used in the design, (2) production drawings and specification, and (3) detailed description of production methods including quality assurance provisions.

This is the final report under Phase II of the contract.

II. AIMS AND OBJECTIVES OF PHASE II

1. Perform physical testing of the bridge web design materials to verify design allowables.
2. Re-evaluate safety margin of bridge web design based upon test results.
3. Develop Engineering drawings of bridge web components.
4. Detailed description of production methods.
5. Order materials for Phase III.
6. Design tooling for Phase III.

III. RESULTS AND CONCLUSIONS

1. Physical testing of the wound bridge web design materials was performed. The tests outlined in the Phase II Material Test Plan were completed as proposed. Results of the in-plane shear test were about 5% lower than target loads for reasons which appeared to be related to sample geometry. F.S.D. proposed to MERADCOM that an additional test be run on the web materials. After approval had been received, F.S.D. manufactured and tested three 3.5 in. diameter by 10.0 in. long tubes whose wall lamination is the same as the bridge web skin. Torsion testing on the tubes proved skin shear strength to be well above design levels. A comparison of test results to computer predictions may be found in Table I.

2. Page 15 of the Phase I Report (released Dec. 8, 1981 contained a failure criterion for the composite bridge web. This failure criterion was re-examined using data generated by testing. Where the original design produced a Factor of Safety of 1.5, the test data produced a Factor of Safety of 1.86.

3. Engineering drawings of the wound bridge web were produced under Phase II and have been reviewed by MERADCOM. Comments generated by that review have been incorporated into revised drawings. These revised drawings are transmitted with this report.

4. Manufacturing materials for Phase III have been ordered. All materials have been received with the exception of aluminum extrusions which are due at F.S.D. by August 15, 1982.

5. Tooling for the eight Phase III full sized panels will be complete by 10 August 1982. Tooling for the filament winding demonstration segment will be completed by 30 August 1982.

6. Bridge tread plates have been cut from existing webs but were found to warp .75 in. over the length and 0.13 over the width. The same vendor who cut the webs will press straighten the tread plates to within 0.25 in. over the length. Tread plates are due at F.S.D. by 10 August 1982.

7. A detailed description of the production of Phase III full size webs is attached to this report. This description is the "Job Card", or step-by-step work instructions which will be given to the Manufacturing Department.

8. The Phase III effort will consist of fabricating eight full scale web sections by lamination of filament wound broadgoods while proving that the filament wound "W" concept is feasible by the use of plywood tooling and a six foot long mandrel. A description of the process is included in this report.

TABLE I

MATERIAL PROPERTIES

DESIGN PROPERTY	COMPUTER PREDICTION	RESULTS OF TESTING
F_{xcu}	29266 PSI	-
F_{ycu}	94129 PSI	66600 PSI*
F_{xyu}	32797 PSI	37368 PSI
E_x	2.65×10^6 PSI	-
E_y	8.471×10^6 PSI	7.182×10^6
G_{xy}	2.561×10^6 PSI	2.553×10^6

* The theoretical is based on strength, whereas, the actual was an instability failure.

IV. TESTING

A. Shear Tests were conducted in accordance with the Phase II Material Test Plan which had been reviewed and accepted by the Army MERADCOM office. Specimen configuration was as shown in Figure 1. Preliminary evaluation of these tests was given in the Monthly Progress Report for May 1, to May 31, 1982, in which low test results were reported. Raw data is presented in Figure 2 and reduced data may be found in Table 2. The average failure load was 41883 lb. compared to the calculated design failure load of 44436 lb. The conclusion reached was that the holes in the Shear Test panel induced a stress concentration which was peculiar to the test panel. Such a stress concentration reduces the failure load an unknown amount.

In order to obtain addition Shear Test data, F.S.D. requested permission from MERADCOM to manufacture and test additional samples which would avoid stress concentrations. The sample chosen was a Torsion Test specimen taken from Air Force Materials Laboratory's Advanced Composites Design Guide of Jan 1971, Page 7.3.18, Specimen (a) which is shown in Figure 3. MERADCOM granted permission, and these samples were built and tested. Torsion Test results may be found in Table 4. The average shear stress measured was 42418 lb./in.^{2}, which may be compared to a design shear stress:

$$\tau_D = \frac{534 \text{ lb./in.}}{.056(.615)} = 15505 \text{ lb./in.}^2$$

The torsion samples, representative of one web skin thickness, exhibited shear strength 2.74 times the design requirement. This is not, however, over design since combined loading failure analysis to be discussed in Section IV reduces the safety factor based on test data to F.S. = 1.86.

Shear modulus was calculated from the strain data of the original shear test panels to be:

$$G_{xy} = \left(\frac{.0353\ P}{wt}\right)\left(\frac{1 + E_1 - E_2}{E_1 + E_2}\right)$$

where P = Load
W = Distance between holes
t = Combined skin thickness
E_1, E_2 = Measured strain

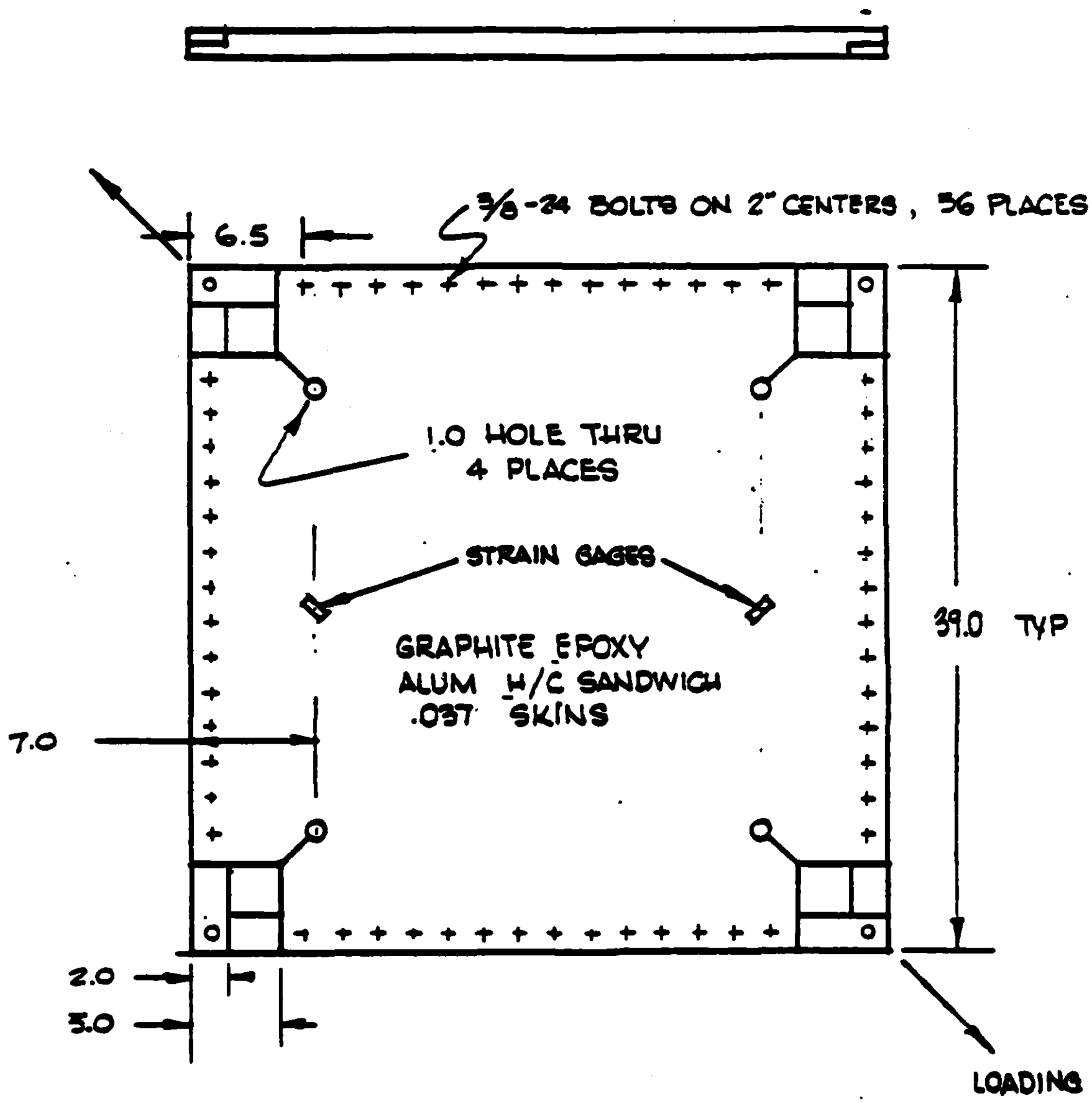


FIGURE 1. SHEAR TEST SPECIMEN

ENGR.			REVISED	DATE	EDO CORPORATION FIBER SCIENCE DIVISION	REPORT
CHECK						PAGE

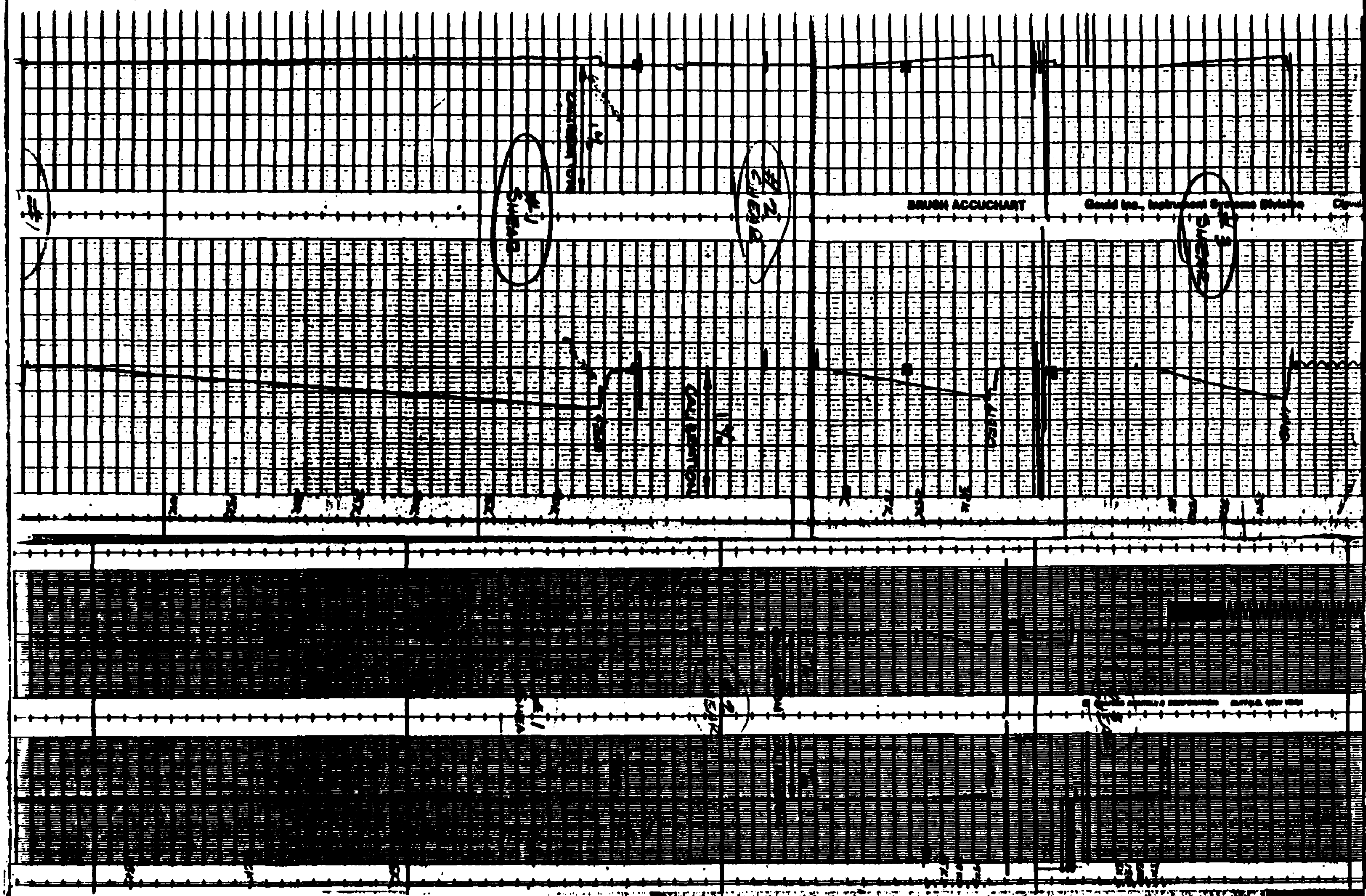


FIGURE 2. RAW SHEAR TEST DATA

TABLE 2

SHEAR TEST DATA

SAMPLE	FAILURE LOAD	GAUGE NUMBER	FAILURE STRAIN
1	42600 LB.	1 - 1	+ 0.26%
		1 - 2	+ 0.30%
		1 - 3	- 0.10%
		1 - 4	- 0.05%
2	41950 LB.	2 - 1	+ 0.25%
		2 - 2	+ 0.21%
		2 - 3	- 0.08%
		2 - 4	- 0.09%
3	41100 LB.	3 - 1	+ 0.24%
		3 - 2	+ 0.24%
		3 - 3	- 0.08%
		3 - 4	- 0.07%

TABLE 3

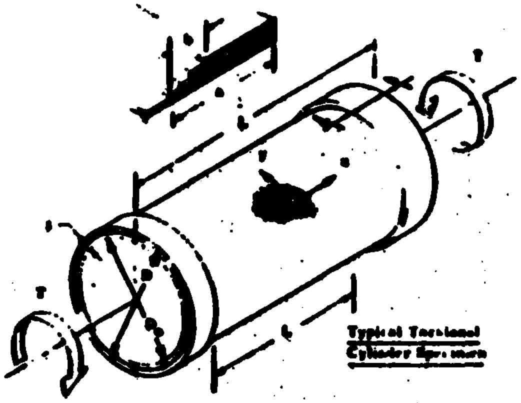
COMPRESSIVE TEST DATA

SAMPLE	FAILURE LOAD	GAUGE NUMBER	FAILURE STRAIN
1	53900 LB.	1 - 1	-0.54%
		1 - 2	-0.40%
		1 - 3	-0.08%
		1 - 4	-0.07%
2	49350 LB.	2 - 1	-0.36%
		2 - 2	-0.41%
		2 - 3	-0.07%
		2 - 4	-0.05%
3	47000 LB.	3 - 1	-0.37%
		3 - 2	-0.46%
		3 - 3	-0.06%
		3 - 4	-0.06%

TEST METHODS SUMMARY - COMPOSITE LAMINATE MECHANICAL PROPERTIES

Test Specimen	Special Remarks

(a)



Method:
Cylinder Torsion, General
Reference 7.6, 7.14

(1) Specimen fabrication may be difficult both from laminate layup and compaction during cure.
(2) Specimen ends may be reinforced or not depending on loading device.
(3) Specimen diameter should be sufficiently large to avoid significant filament bending stresses from wrapping.
(4) Torque stress in laminate:

$$f_{xy}^{s} = \frac{16TD}{\pi(D^4 - D_o^4)} \text{ or } \frac{2T}{\pi t D^2} \text{ for } t << D$$

(5) Modulus of laminate:

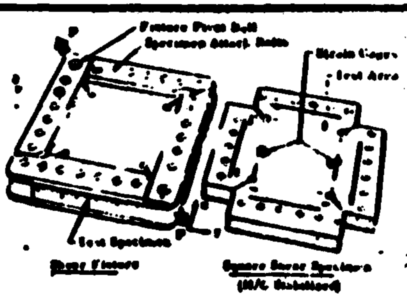
$$G_{xy} = \frac{32T\ell}{\pi(D^4 - D_o^4)\theta_T} \text{ or } \frac{4T\ell}{\pi t D^3 \theta_T} \text{ for } t << D$$

where θ_T is the angular twist in radians over length ℓ.

Specimen Dimensions

Source	Fiber Orient.	D inches	t inches	ℓ inches	a inches	b inches
Ref 8.17	0°	1.0	0.030	4.0	1.3	0.3
	±45° or 90°	2.0	0.030	4.0	1.3	0.3
Ref 8.18	General	3.08	0.14	11.0	2.5	Radius

(b)



Method:
NR Slotted Picture Frame
Reference 7.15

(1) Specimen must be designed or reinforced to preclude bearing failures at attach bolts.
(2) Best location of strain gages, parallel and perpendicular to loading, shown in sketch.
(3) Shear is calculated by equation

$$G_{xy} = \left(\frac{0.3531P}{wt}\right)\left(\frac{1 + \epsilon_1 - \epsilon_2}{\epsilon_1 + \epsilon_2}\right)$$

where ϵ_1 and ϵ_2 are strains in inches/inch with $+\epsilon$ indicating extensional strain.

FIGURE 3. SHEAR TESTS FROM AFML ADVANCED COMPOSITES DESIGN GUIDE

TABLE 4

TORSION TESTS

1. 2750
2. 3303
3. 3008

$\bar{x} = 3020.33$

$$\tau = \frac{2T}{\pi t D^2}$$

$T = 3020\ (10.0) = 30200$ in.lbs.

$$\tau = \frac{2(30200)}{\pi(.037)(3.5)^2} = 42418 \text{ lb./in.}^2$$

The following shear moduli were calculated:

	SAMPLE #1	SAMPLE #2	SAMPLE #3	AVERAGE
Calculated G_{xy}, PSI	2.380×10^6	2.693×10^6	2.587×10^6	2.553×10^6

Design G_{xy} was 2.561×10^6 PSI.

B. Compression Tests were conducted as outlined by the Phase II Material Test Plan. Specimen configuration is shown in Figure 4. Raw test data may be found in Figure 5, and reduced data appears in Table 1.

While the test results exceeded design requirements, they were lower than computer predictions because they failed in a different mode than anticipated.

Test data recorded on the narrow chart is unaccountably low, about 1/5 the expected level of strain. It is suspected that a calibration error occurred.

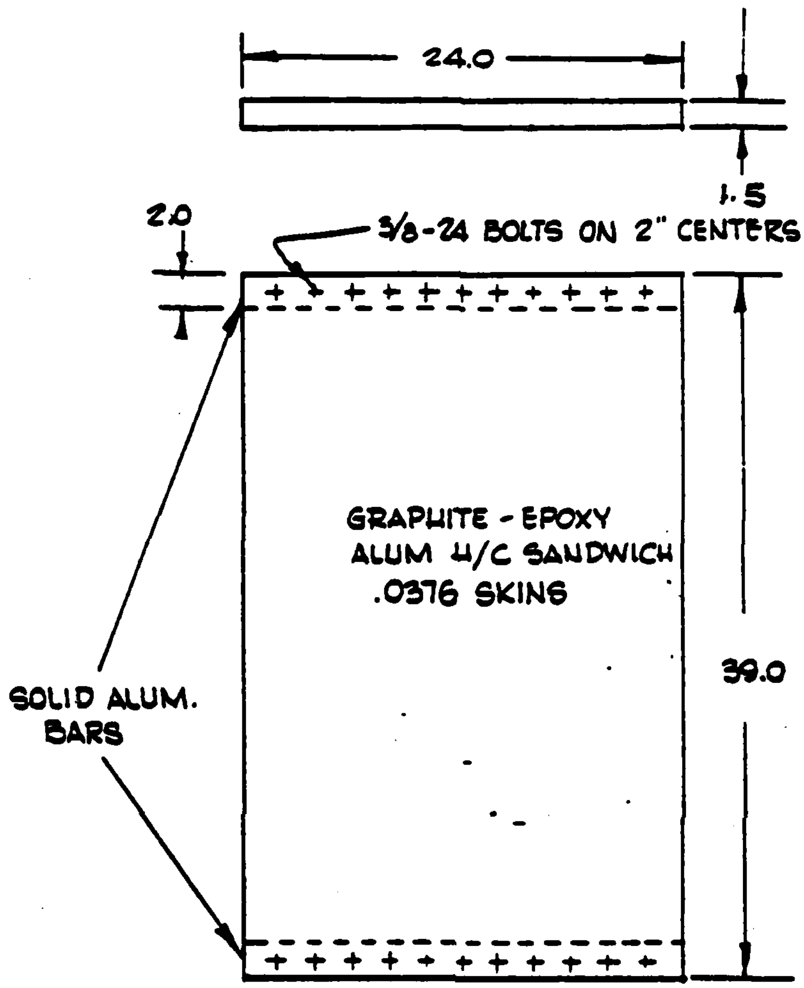


FIGURE 4. COMPRESSION TEST SPECIMENS

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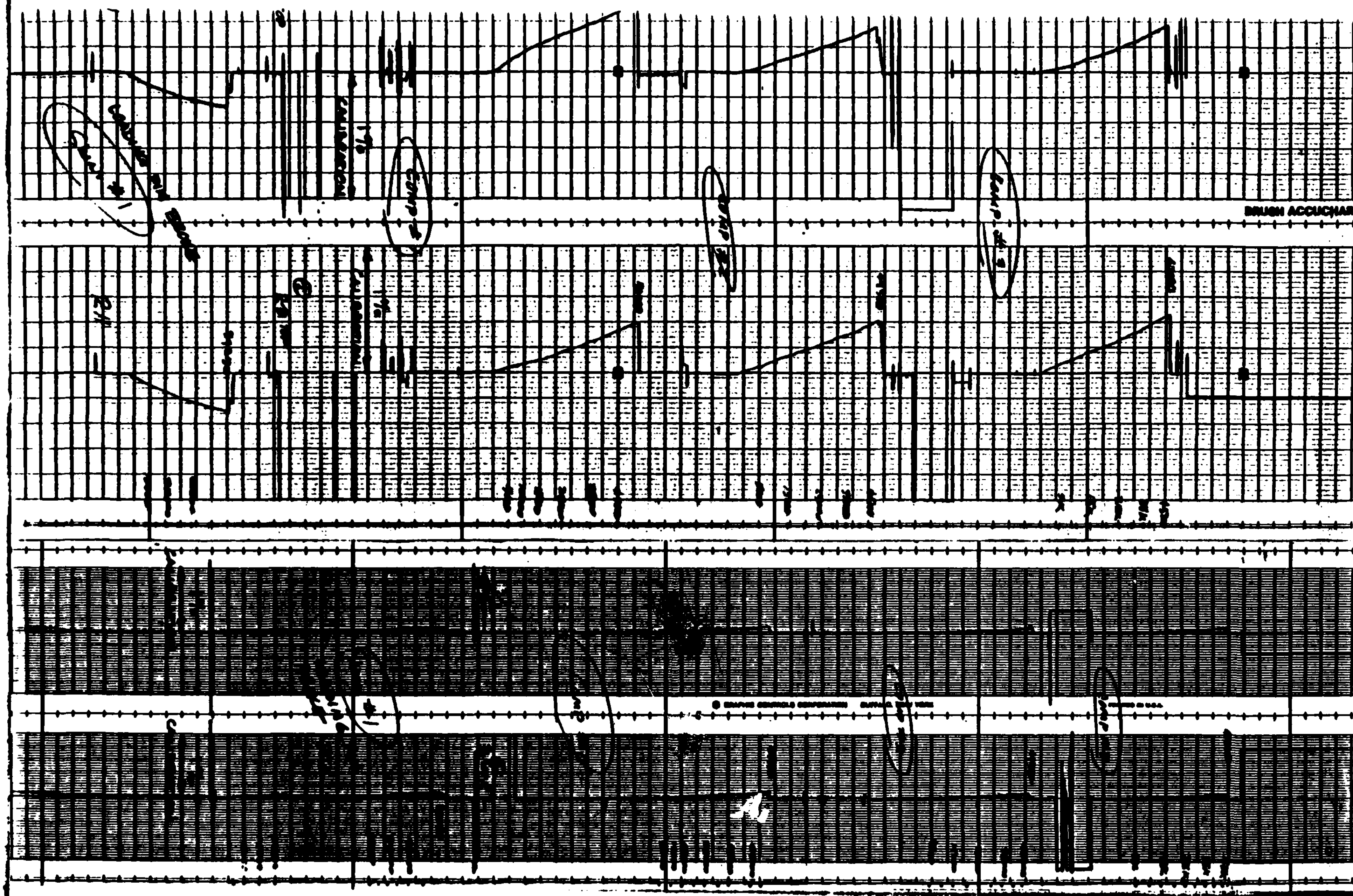

FIGURE 5. RAW COMPRESSIVE TEST DATA

V. TEST DATA-BASED SAFETY MARGIN

FAILURE ANALYSIS CRITERION

$$\left(\frac{\sigma_x}{F_x}\right)^2 + \left(\frac{\sigma_y}{F_y}\right)^2 - \left(\frac{\sigma_x \sigma_y}{F_x F_y}\right) + \left(\frac{\tau}{F_{xy}}\right)^2 = 1.0 \text{ AT FAILURE}$$

$$\left(\frac{\sigma_x}{F_x}\right) = 1.0 \text{ AT FAILURE}$$

$$\left(\frac{\sigma_y}{F_y}\right) = 1.0 \text{ AT FAILURE}$$

FROM TEST DATA $\quad \sigma_y = \frac{1514}{.074} = 20{,}459 \;; \quad \tau = \frac{534}{.074} = 7216$

$$\left(\frac{5353}{.615(29266)}\right)^2 + \left(\frac{20459}{.615(66600)}\right)^2 - \left(\frac{5353(20459)}{.615^2(29266)(66600)}\right) + \left(\frac{7216}{37368(.615)}\right)^2$$

$$= 0.288$$

$$F.S. = \frac{1}{\sqrt{.2880}} = 1.86$$

$$\left(\frac{\sigma_x}{F_x}\right) = \left(\frac{5353}{.615(29266)}\right) = 0.30$$

$$\left(\frac{\sigma_y}{F_y}\right) = \left(\frac{20459}{.615(66600)}\right) = 0.50$$

THEREFORE THE DESIGNED BRIDGE WEB WOULD NOT FAIL UNDER DESIGN LOADS.

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VI. FILAMENT WINDING PROCESS DEMONSTRATION

1. Tooling

   The mandrel will be made from 1/2 inch plywood with piano type hinges, about six feet long, with full width webs.

2. Demonstration winding will be with graphite fiber, epoxy resin and aluminum honeycomb. Winding sequence will be as follows:

   a. Wind inner skin (90^0, $\pm 45^0$)

   b. Apply 120 glass cloth

   c. Apply honeycomb

   d. Apply 120 glass cloth

   e. Wind outer skin ($\pm 45^0$, 90^0)

   f. "B" stage to formable, tacky resin consistency

   g. Cut skin and fold mandrel into "W" configuration

   h. Secure into proper position

   i. Cure

END

FILMED

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